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**NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS**

# **WARTIME REPORT**

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HIGH-PERFORMANCE FUELS IN A CFR ENGINE**

**II - BLENDS OF 2,2,3-TRIMETHYLPENTANE WITH 28-R**

By Henry E. Alquist and Leonard K. Tower

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

THE EFFECT OF COMPRESSION RATIO ON KNOCK LIMITS OF

HIGH-PERFORMANCE FUELS IN A CFR ENGINE

II - BLENDS OF 2,2,3-TRIMETHYLPENTANE WITH 28-R

By Henry E. A'quist and Leonard K. Tower

SUMMARY

The knock-limited performance of blends of 0, 50, and 100 percent by volume of 2,2,3-trimethylpentane in 28-R fuel was determined with a modified T-4 engine at three sets of conditions varying from severe to mild at each of three compression ratios (6.0, 8.0, and 10.0). A comparison of the knock-limited performance of 2,2,3-trimethylpentane with that of triptane (2,2,3-trimethylbutane) is included.

The knock-limited performance of 2,2,3-trimethylpentane was usually more sensitive to either compression ratio or inlet-air temperature than 28-R fuel, but the ratio of the knock-limited indicated mean effective pressure of a given blend containing 2,2,3-trimethylpentane and 28-R to the indicated mean effective pressure of 28-R alone was not greatly affected by compression ratio if the engine operating conditions were mild. Although 2,2,3-trimethylpentane in general had a lower knock-limited performance than triptane, the characteristics of the two fuels were somewhat similar.

INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, a general program is being conducted at the NACA laboratory, Cleveland, Ohio, to investigate the knock-limited performance of a selected group of high-performance components of aviation fuels. In reference 1 the effects of compression ratio and inlet-air temperature on the knock-limited performance of triptane (2,2,3-trimethylbutane) were emphasized. The present paper describes

the relative effects of compression ratio and inlet-air temperature on the knock-limited performance characteristics of 2,2,3-trimethylpentane based on CFR engine tests conducted during October 1944. The relative merits of 2,2,3-trimethylpentane and triptane are discussed. A correlation of the effects of compression ratio and inlet-air temperature on the knock-limited performance characteristics of 2,2,3-trimethylpentane according to the method proposed in reference 2 is also presented as a substantiating check of the proposed method.

#### APPARATUS AND TEST PROCEDURE

A CFR engine coupled to a 100-horsepower, direct-current, cradle-type dynamometer, the same as that in the first phase of this program (reference 1), was used to obtain the data presented herein. At each of three compression ratios, 6.0, 8.0, and 10.0, data were obtained at three sets of operating conditions:

Condition	Inlet-air temperature (°F)	Coolant temperature (°F)	Spark advance (deg B.T.C.)
1 (severe)	225	375	45
2 (medium)	250	250	30
3 (mild)	150	250	30

Except for compression ratio, engine conditions 1, 2, and 3 correspond to the F-4, modified A, and modified B conditions, respectively, used in reference 3. Other engine conditions correspond to specification CRC-F-4-443. On each day, blends of 0, 50, and 100 percent by volume 2,2,3-trimethylpentane in 28-R fuel were tested at one of the three compression ratios and a single operating condition.

Because of preignition difficulties associated with the prevailing high power levels, the data for the 100-percent blend at a compression ratio of 6.0 and at low inlet-air temperatures are incomplete in the rich-mixture region.

#### RESULTS AND DISCUSSION

Knock-limited performance data for the blends are shown in figures 1, 2, and 3 and are tabulated in table I for four fuel-air

ratios. These data indicate that the ratio of the knock-limited indicated mean effective pressure of either 2,2,3-trimethylpentane or the 50-percent blends to the indicated mean effective pressure of 28-R fuel was not greatly affected by compression ratio at mild engine operating conditions (condition 3). As the severity of engine conditions was increased (conditions 2 and 1), the percentage increase in knock-limited power resulting from the substitution of 2,2,3-trimethylpentane for 28-R rapidly decreased. A 100-percent blend of 2,2,3-trimethylpentane at condition 1 gave an improvement from 100 to 150 percent (depending on fuel-air ratio) at a compression ratio of 6.0, whereas at a compression ratio of 10.0 the greatest permissible gain was 24 percent.

Table II shows the effect of compression ratio upon the temperature sensitivity of 2,2,3-trimethylpentane and 28-R blends. As the compression ratio was increased, all the blends showed more and more change in knock-limited indicated mean effective pressure with an accompanying variation in inlet-air temperature of 100° F. The percentage improvement in power, when the compression ratio was 6.0 and the inlet-air temperature was lowered from 250° to 150° F, for 2,2,3-trimethylpentane was about the same as or a little lower than for 28-R fuel; at a compression ratio of 10.0, the percentage improvement afforded by 2,2,3-trimethylpentane due to this lowering of inlet-air temperature was nearly three times the improvement obtained with 28-R fuel.

Figure 4 is a cross plot of compression ratio against knock-limited indicated mean effective pressure at mild, medium, and severe engine conditions for blends of 0, 50, and 100 percent 2,2,3-trimethylpentane and 28-R fuel. These data indicate that, if 2,2,3-trimethylpentane blends are used in a high-compression-ratio engine, the other operating conditions must be mild if the benefits in increased knock-limited indicated mean effective pressure of 2,2,3-trimethylpentane are to be realized. (Cf. figs. 4(a) and 4(c).) The study of triptane (2,2,3-trimethylbutane) blended with 28-R (reference 1) resulted in a similar conclusion.

On the assumption that the compression-gas density and temperature can be used in place of the densities and temperatures which directly influence the knocking reaction, a correlation was drawn in reference 2 of the effects of compression ratio and inlet-air temperature upon the knock-limited performance of a CFR engine. In order to obtain this correlation, the knock-limited compression-air density, when the piston is at top center, was plotted against the compression-air temperature as calculated by adiabatic formulas. In terms of cylinder displacement and compression ratio, the compression-air density was calculated from the following equation:

$$\rho = \frac{A(r-1)}{nv_d}$$

where

$\rho$  compression-air density, pounds per cubic inch

$A$  intake-air flow, pounds per minute

$n$  intake cycles per minute

$r$  engine compression ratio

$v_d$  engine displacement, cubic inches

Although the effects of engine operating characteristics, such as fuel vaporization, heat transfer to the cylinder walls, fuel-air ratio, and preflame reactions, were not taken into account when the equation for calculating compression temperature was derived in terms of adiabatic compression, a satisfactory correlation was obtained. The equation for determining the approximate temperature was defined in reference 2 as follows:

$$T = T_0 r^{(\gamma-1)}$$

where

$T$  compression-air temperature,  $^{\circ}\text{R}$

$T_0$  intake-air temperature,  $^{\circ}\text{R}$

$\gamma$  ratio of specific heats of charge at constant pressure and constant volume

An application of this correlation is shown in figure 5. A three-dimensional graph illustrating the progressive change in the relation between knock-limited compression-air density and temperature with fuel composition is shown in figure 6. The usually greater slope of the 2,2,3-trimethylpentane curve over the 28-R curve, especially apparent at lean mixtures, indicates the increased sensitivity of 2,2,3-trimethylpentane to either compression ratio or inlet-air temperature.

A general indication of the relative merits of 2,2,3-trimethylpentane and triptane at two fuel-air ratios is given as a function of compression ratio in figure 7. (The triptane data for this figure were taken from reference 1.) As shown in reference 4 and by the results of research in other laboratories, 2,2,3-trimethylpentane generally has a lower knock-limited performance than triptane, although the characteristics of the two fuels are somewhat similar.

#### CONCLUDING REMARKS

Knock-limited tests at severe, medium, and mild operating conditions with a modified F-4 engine of 2,2,3-trimethylpentane, triptane (2,2,3-trimethylbutane), and 28-R fuel indicate the following:

1. The knock-limited performance of 2,2,3-trimethylpentane was usually more sensitive to either compression ratio or inlet-air temperature than 28-R fuel but the ratio of the knock-limited indicated mean effective pressure of a given blend containing 2,2,3-trimethylpentane and 28-R to the indicated mean effective pressure of 28-R alone was not greatly affected by compression ratio if the engine operating conditions were mild.
2. Although 2,2,3-trimethylpentane in general had a lower knock-limited performance than triptane, the characteristics of the two fuels were somewhat similar.
3. These tests provide further evidence that a satisfactory correlation of the effects of compression ratio and inlet-air temperature upon the knock-limited performance of fuels in a CFR engine can be obtained by plotting the knock-limited compression-air densities at the various conditions against the compression-air temperatures.

Aircraft Engine Research Laboratory,  
National Advisory Committee for Aeronautics,  
Cleveland, Ohio, January 10, 1945.

#### REFERENCES

1. Alquist, Henry E., and Tower, Leonard K.: The Effect of Compression Ratio on Knock Limits of High-Performance Fuels in a CFR Engine. I - Blends of Triptane and 28-R Fuel. NACA MR No. E4J10, 1944.
2. Evvard, John C., and Branstetter, J. Robert: A Correlation of the Effects of Compression Ratio and Inlet-Air Temperature on the Knock Limits of Aviation Fuels in a CFR Engine - I. NACA ACR No. E5D20, 1945.
3. Evvard, John C., Imming, Harry S., and Genco, Russell S.: Knock-Limited Blending Characteristics of Blends of Triptane and 28-R Aviation Fuel. NACA Memo. rep., April 18, 1944.
4. Jones, Anthony W., and Bull, Arthur W.: Knock-Limited Performance of Pure Hydrocarbons Blended with a Base Fuel in a Full-Scale Aircraft-Engine Cylinder. I - Eight Paraffins, Two Olefins. NACA ARR No. E4E25, 1944.

TABLE I - EFFECT OF COMPRESSION RATIO ON THE KNOCK-LIMITED PERFORMANCE OF 28-R FUEL WITH AND WITHOUT THE ADDITION OF 2,2,3-TRIMETHYLPENTANE AT THREE SETS OF ENGINE CONDITIONS

Condition 1: inlet-air temperature, 225° F; coolant temperature, 375° F;  
spark advance, 45° B.T.C.  
Condition 2: inlet-air temperature, 250° F; coolant temperature, 250° F;  
spark advance, 70° B.T.C.  
Condition 3: inlet-air temperature, 150° F; coolant temperature, 250° F;  
spark advance, 30° B.T.C.

Percentage 2,2,3-tri- methylpentane in 28-R <sup>a</sup>	imep ratio <sup>b</sup>											
	F/A = 0.0625			F/A = 0.070			F/A = 0.090			F/A = 0.110		
	Condition			Condition			Condition			Condition		
	1	2	3	1	2	3	1	2	3	1	2	3
Compression ratio, 6.0												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.37	1.48	1.46	1.37	1.59	1.49	1.50	1.52	1.43	1.46	1.43	1.46
100	1.96	2.55	2.51	2.54	2.66	2.52	2.46	2.49	2.35	2.41	2.22	----
Compression ratio, 8.0												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.28	1.43	1.49	1.26	1.33	1.50	1.25	1.53	1.46	1.43	1.49	1.43
100	1.67	1.97	2.42	1.60	2.04	2.52	1.82	2.34	2.36	2.43	2.37	2.18
Compression ratio, 10.0												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
50	1.00	1.16	1.45	1.00	1.11	1.48	1.00	1.20	1.46	1.11	1.43	1.51
100	1.00	1.39	2.21	1.00	1.30	2.25	1.09	1.59	2.40	1.24	2.38	2.48

<sup>a</sup>All blends leaded to 4.53 ml TEL/gal.

<sup>b</sup>imep ratio =  $\frac{\text{imep blend}}{\text{imep 28-R}}$

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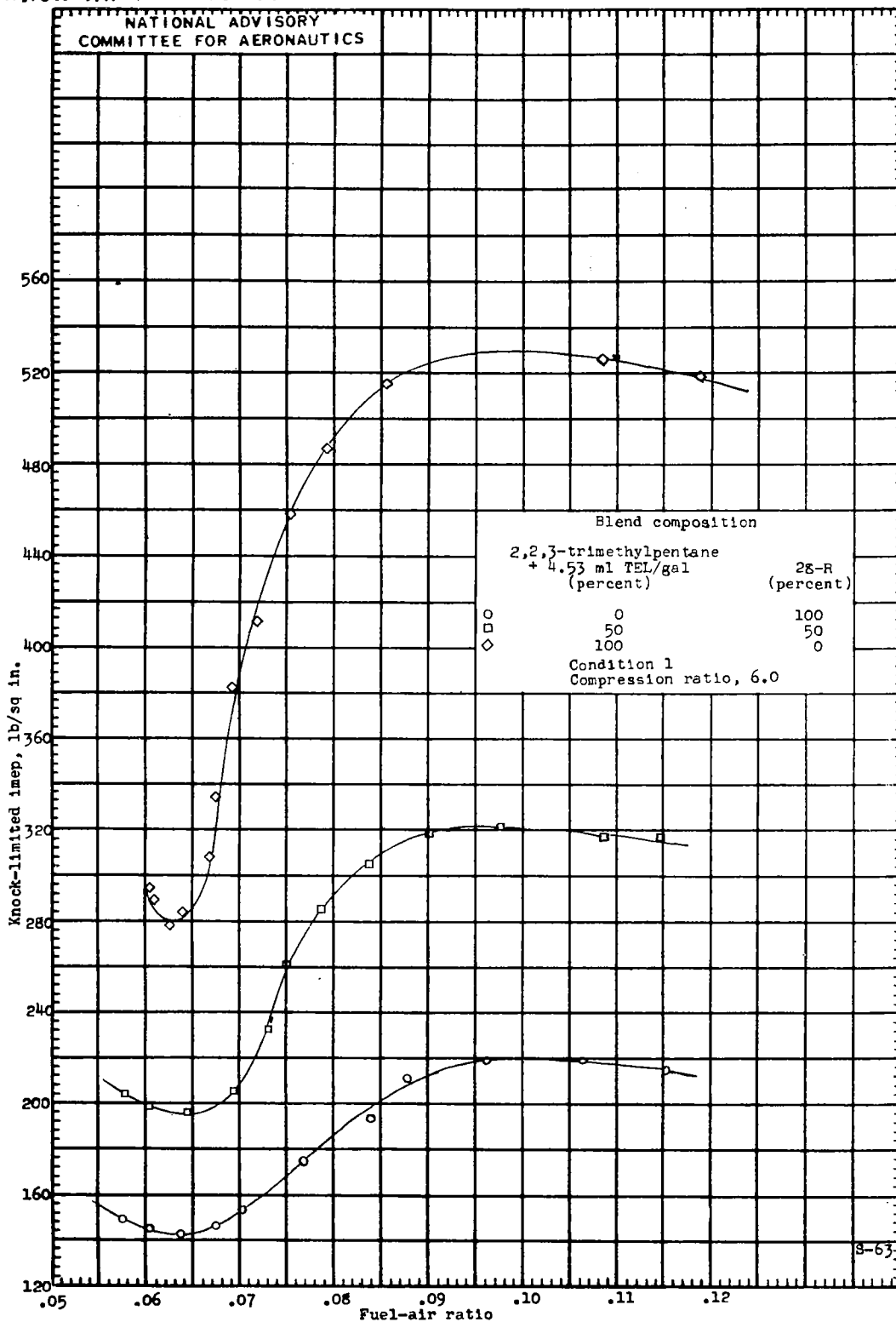
TABLE II - EFFECT OF INLET-AIR TEMPERATURE ON THE KNOCK LIMITS OF BLENDS CONTAINING

2,2,3-TRIMETHYLPENTANE AND 28-R FUEL AT THREE COMPRESSION RATIOS

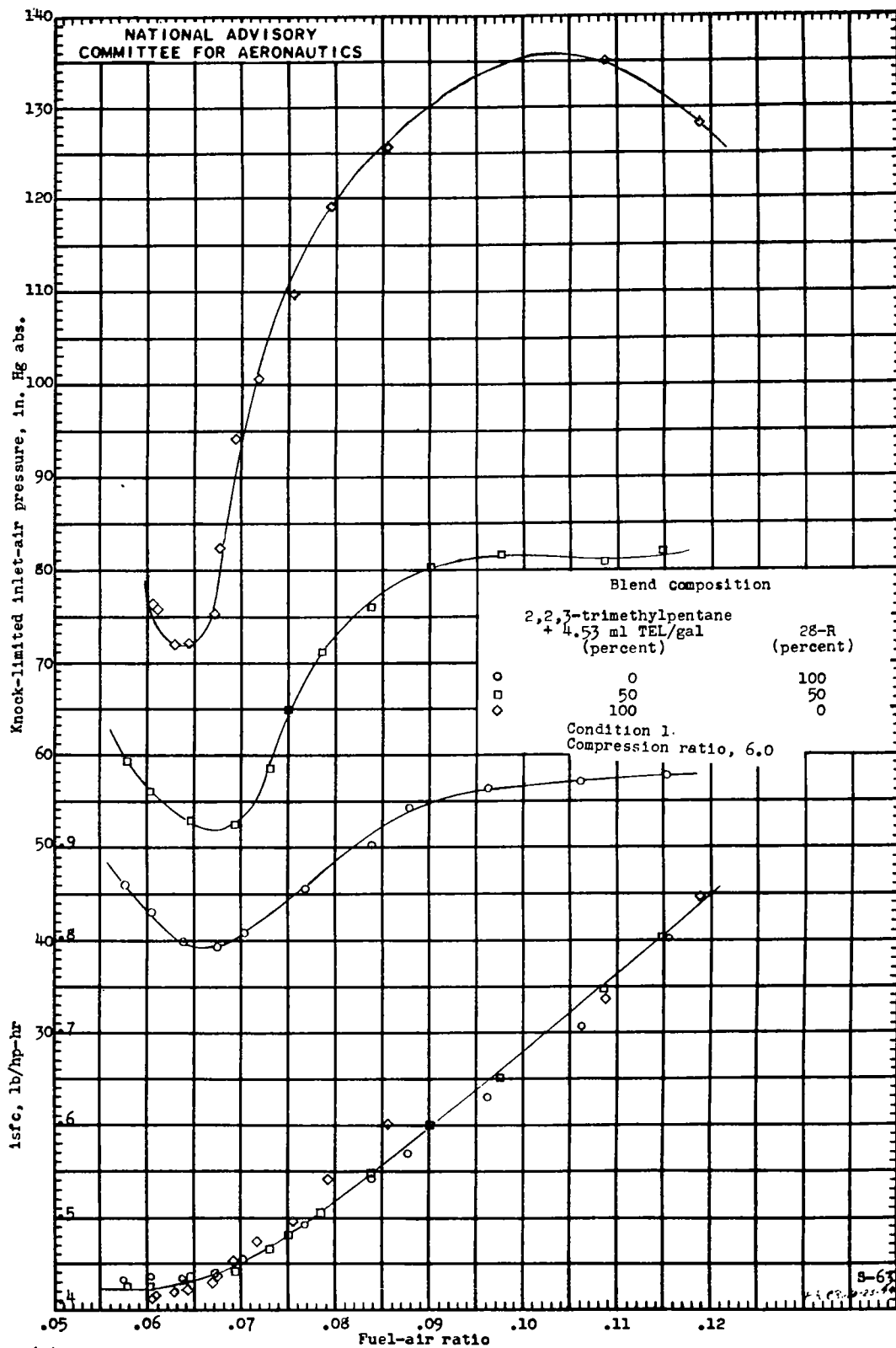
[F-4 engine operating at modified conditions: inlet-air temperatures, 150° and 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.]

Percentage 2,2,3-tri- methylpentane in 28-R <sup>a</sup>	F/A = 0.0625		F/A = 0.070		F/A = 0.080		F/A = 0.090	
	imep ratio <sup>b</sup>	imep differ- ence <sup>c</sup>	imep ratio <sup>b</sup>	imep differ- ence <sup>c</sup>	imep ratio <sup>b</sup>	imep differ- ence <sup>c</sup>	imep ratio <sup>b</sup>	imep differ- ence <sup>c</sup>
Compression ratio, 6.0								
0	1.19	35	1.18	34	1.12	26	1.08	19
50	1.17	47	1.10	31	1.05	16	1.02	7
100	1.17	80	1.11	53	1.02	12	1.02	12
Compression ratio, 8.0								
0	1.27	36	1.25	35	1.18	30	1.12	23
50	1.32	62	1.42	77	1.23	56	1.07	20
100	1.55	146	1.55	155	1.28	106	1.13	55
Compression ratio, 10.0								
0	1.51	44	1.51	45	1.42	46	1.21	29
50	1.87	89	2.01	99	1.79	100	1.47	79
100	2.40	169	2.59	184	2.36	211	1.93	186

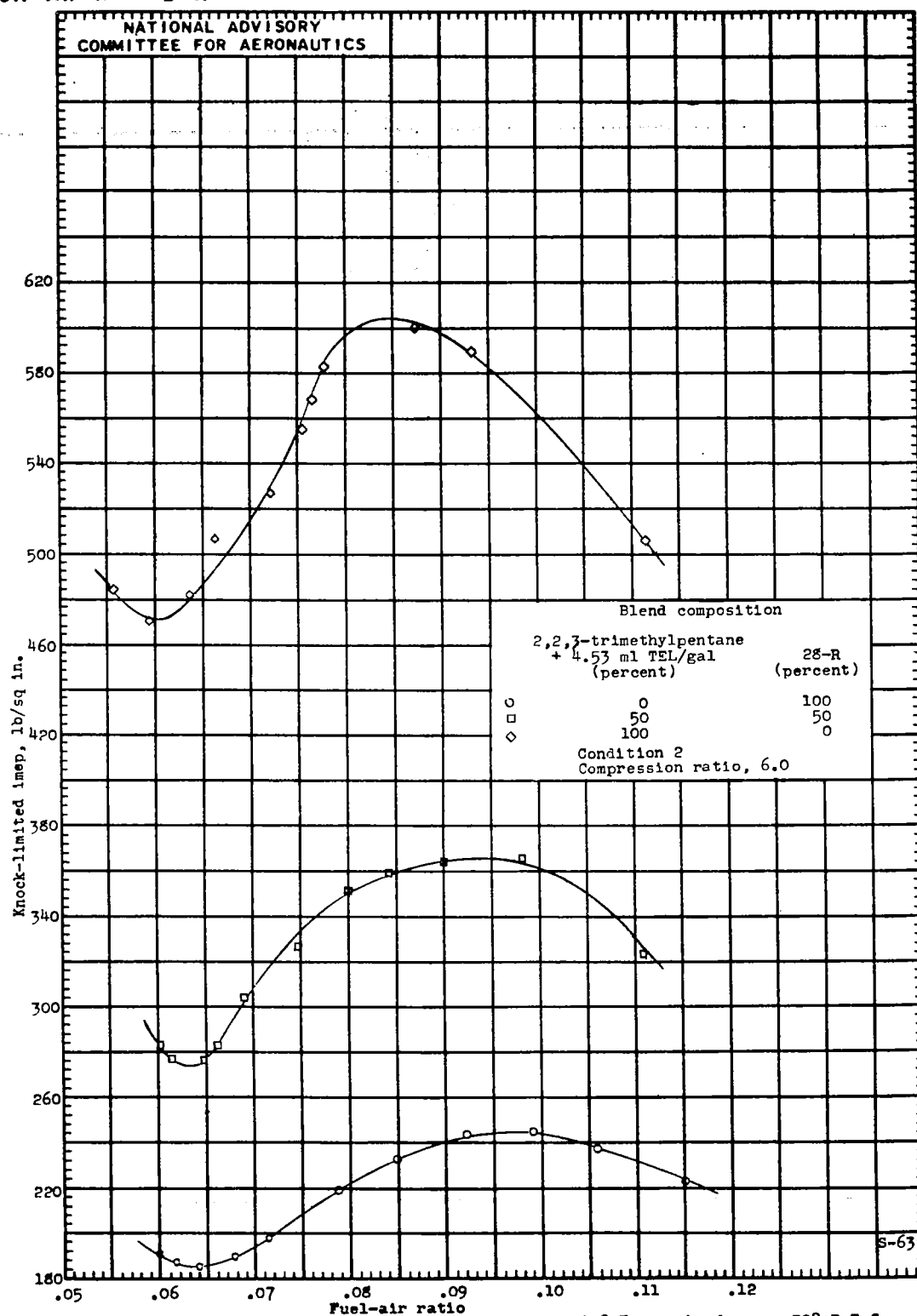
<sup>a</sup>All blends leaded to 4.53 ml TEL/gal.<sup>b</sup>imep ratio = imep<sub>150</sub>/imep<sub>250</sub>.<sup>c</sup>imep difference = imep<sub>150</sub> - imep<sub>250</sub>.National Advisory Committee  
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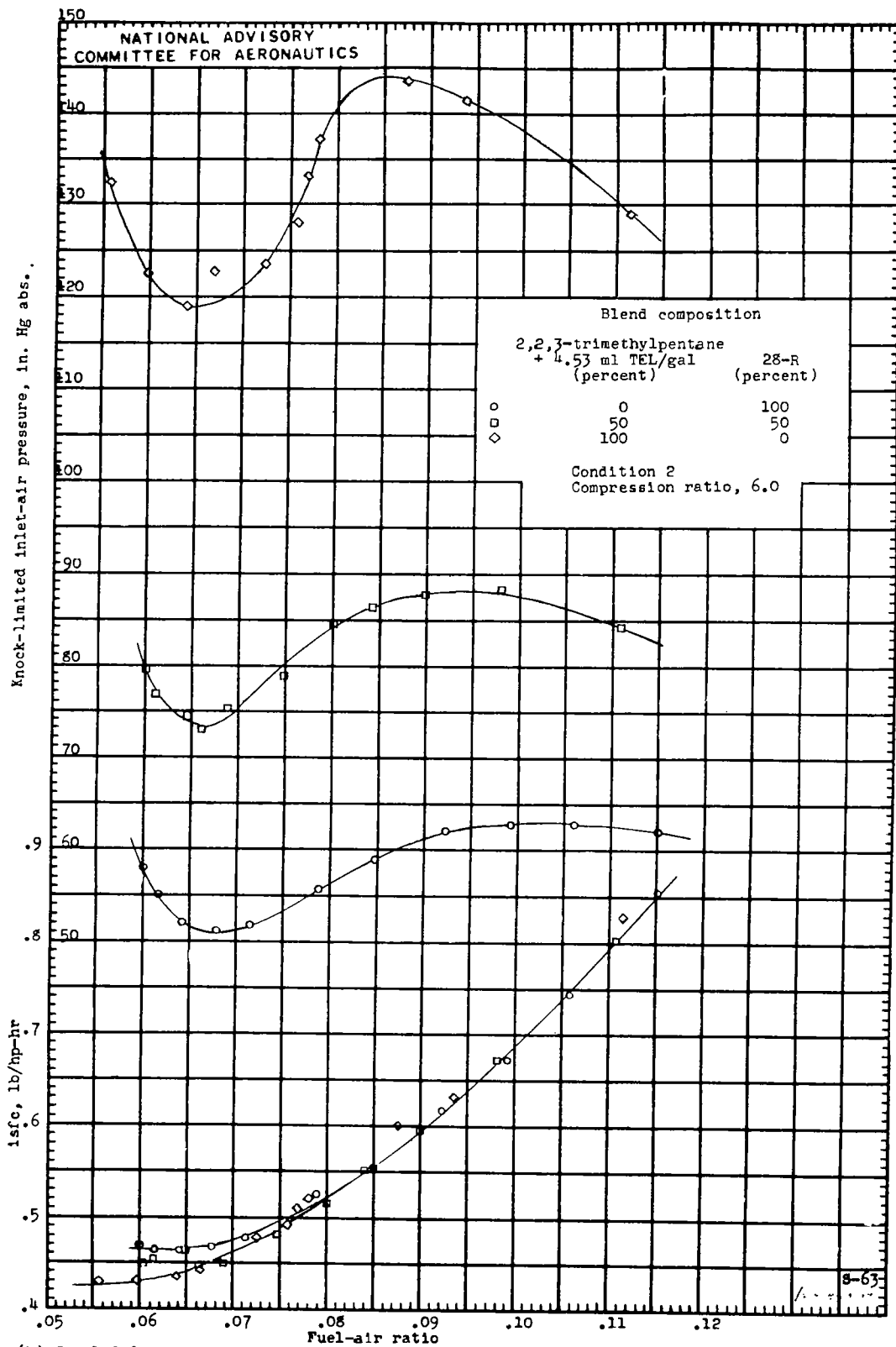
(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.  
Figure 1. - Knock-limited performance of blends of 2,2,3-trimethylpentane and 28-R fuel  
in CFR engine at compression ratio of 6.0. Engine speed, 1800 rpm; oil temperature, 165° F.



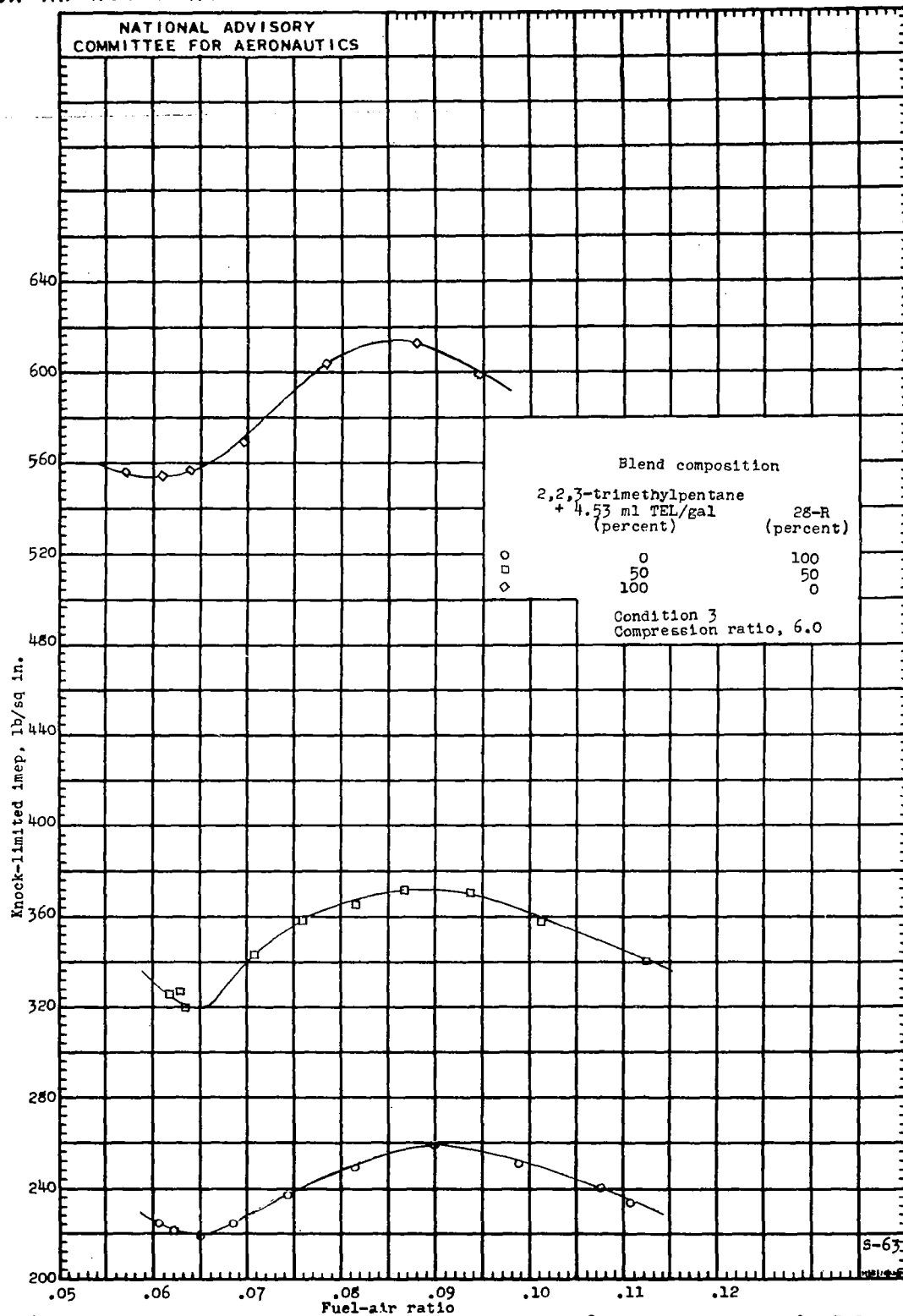
(a) Concluded.  
Figure 1. - Continued.



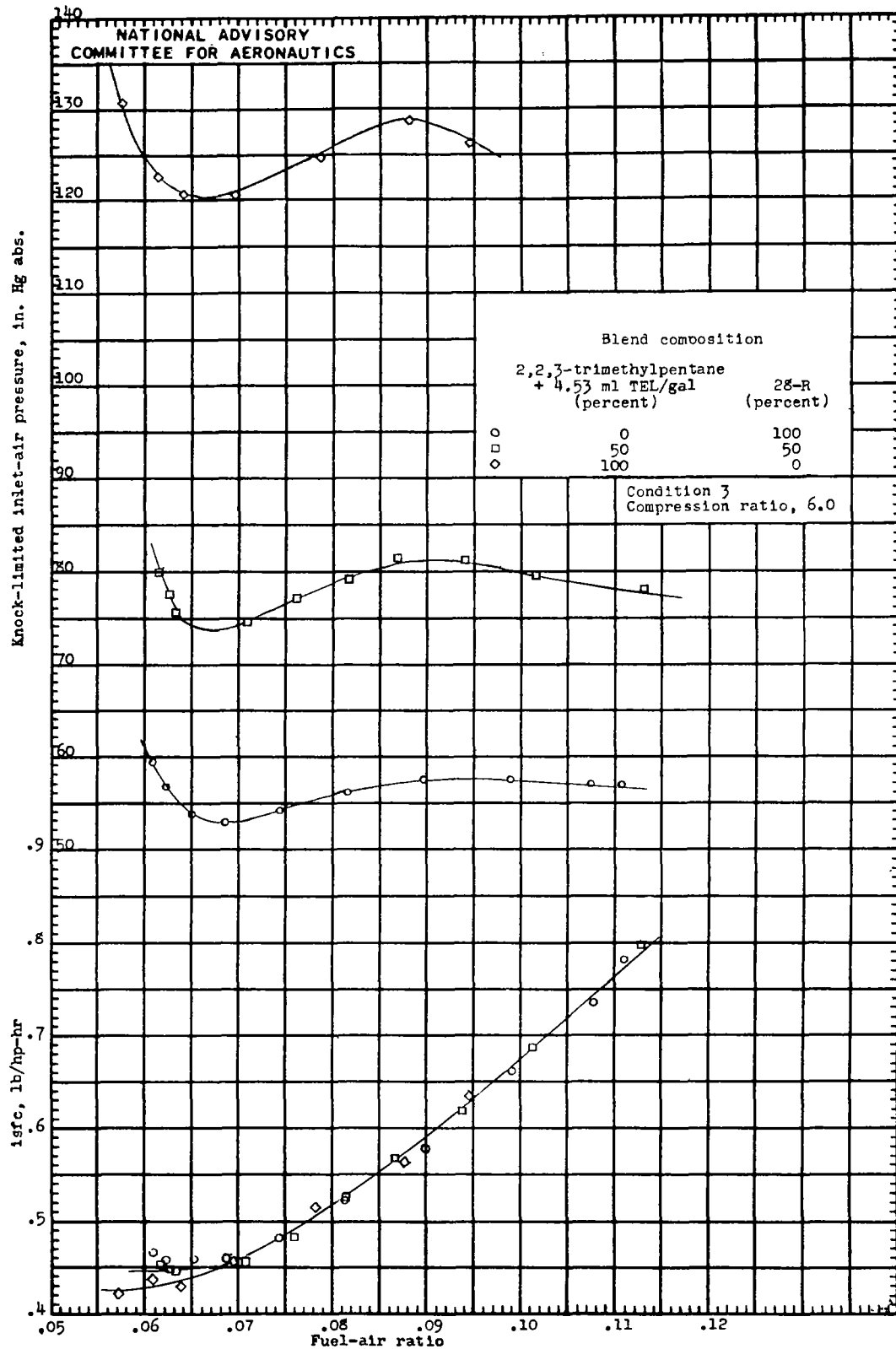
(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 1. - Continued.



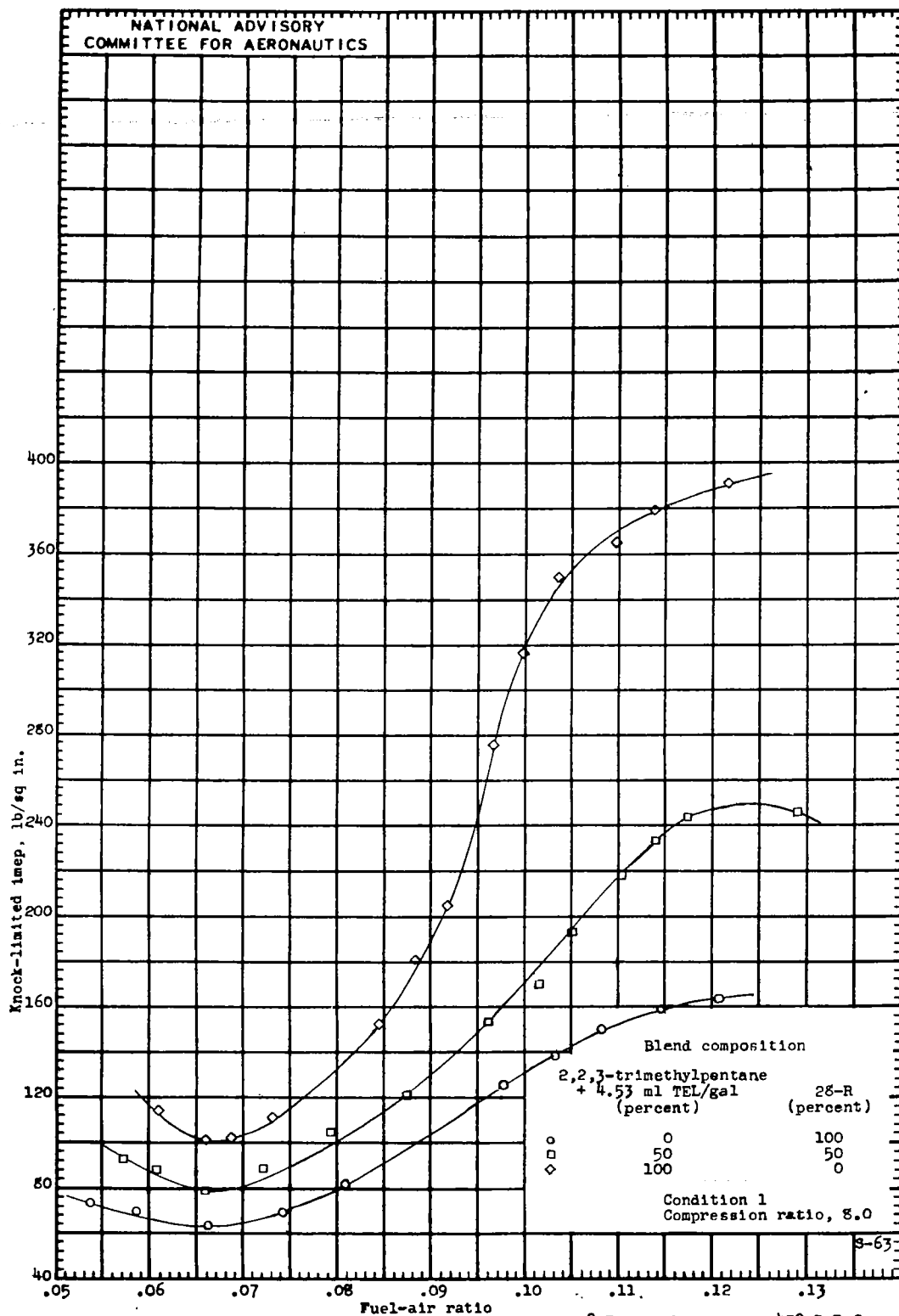
(b) Concluded.  
Figure 1. - Continued.



(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 1. - Continued.

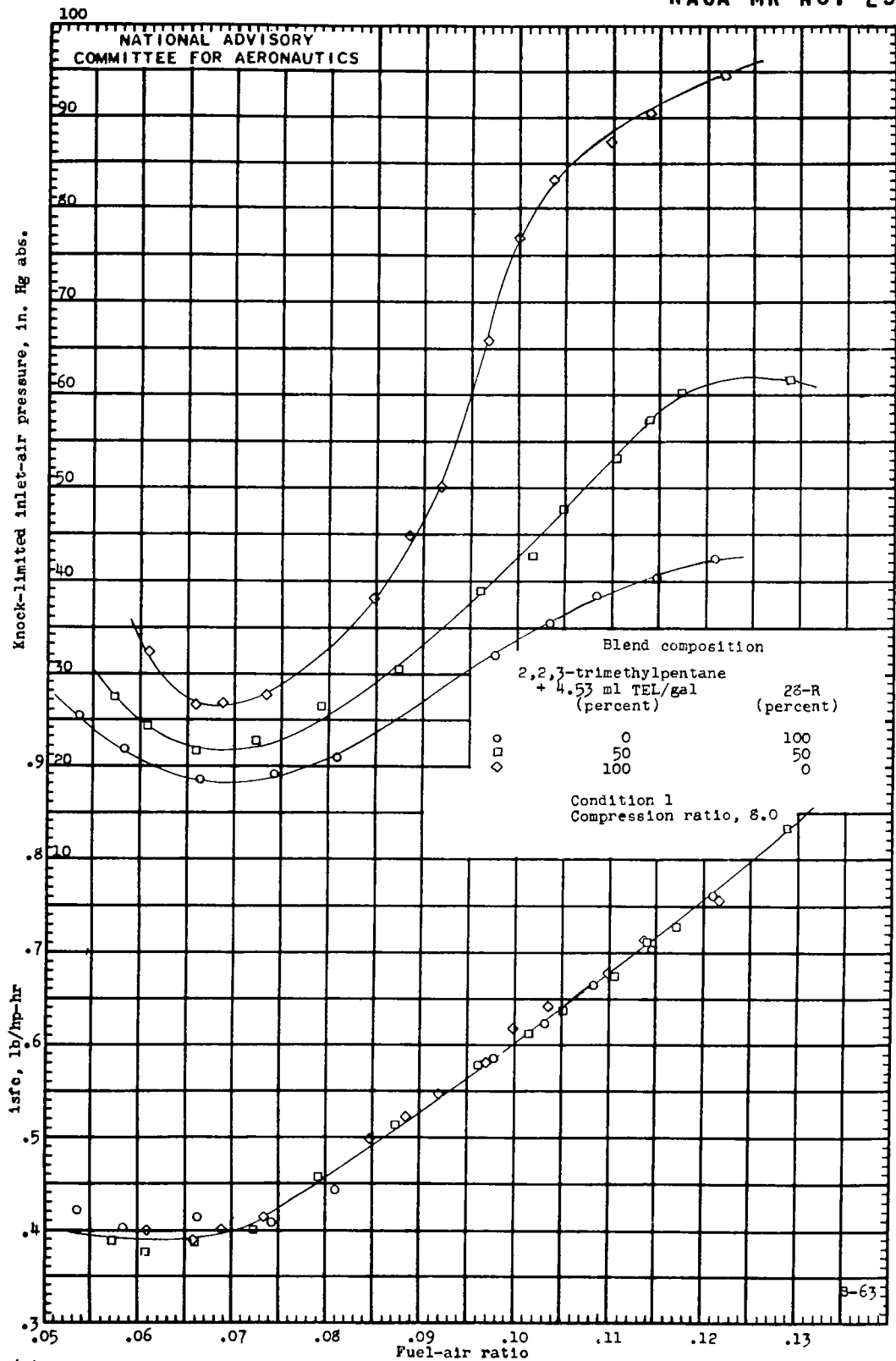


(c) Concluded.  
Figure 1. - Concluded.

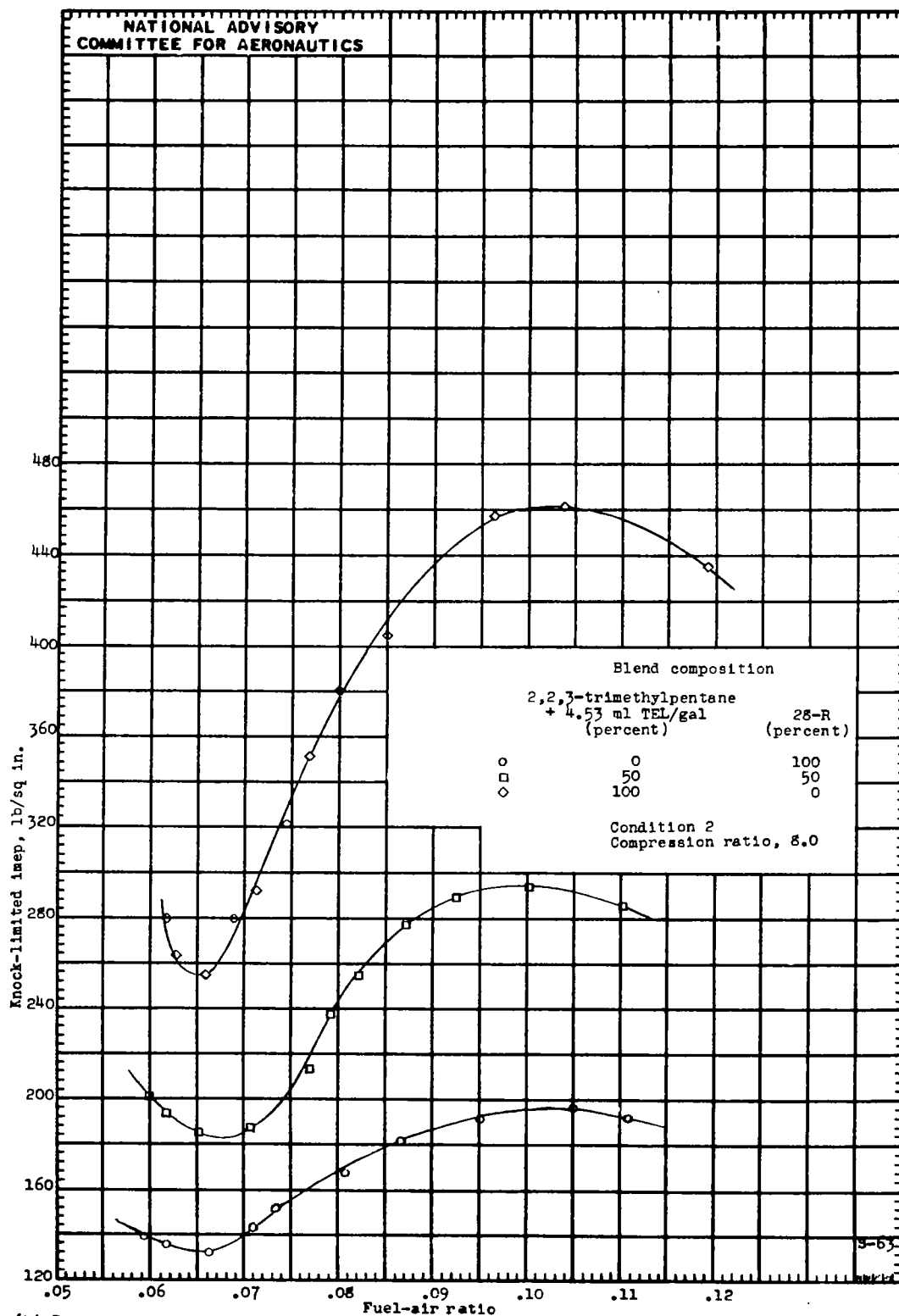


(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.  
Figure 2. - Knock-limited performance of blends of 2,2,3-trimethylpentane and 25-R fuel  
in CFR engine at compression ratio of 8.0. Engine speed, 1800 rpm; oil temperature,  
165° F.

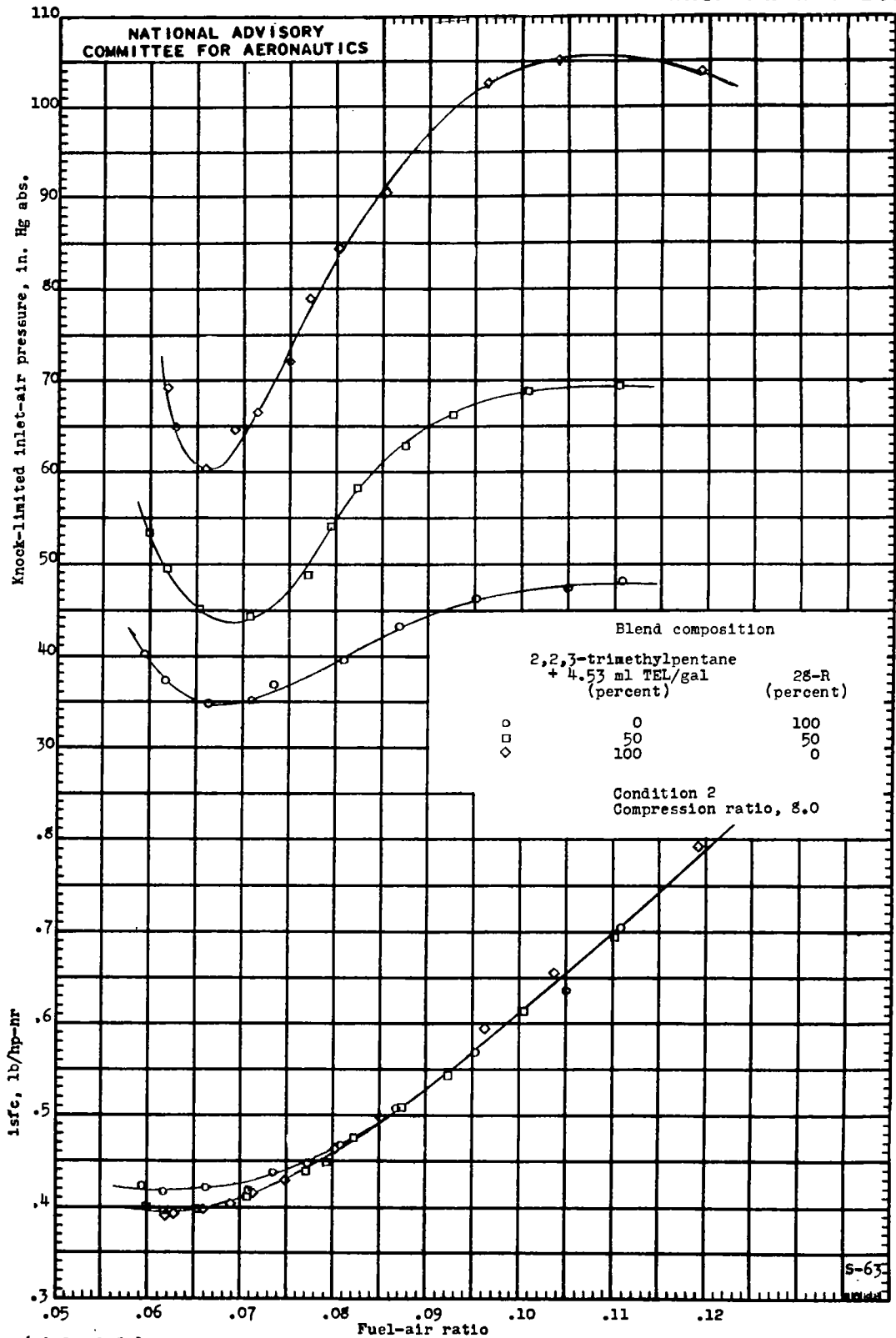




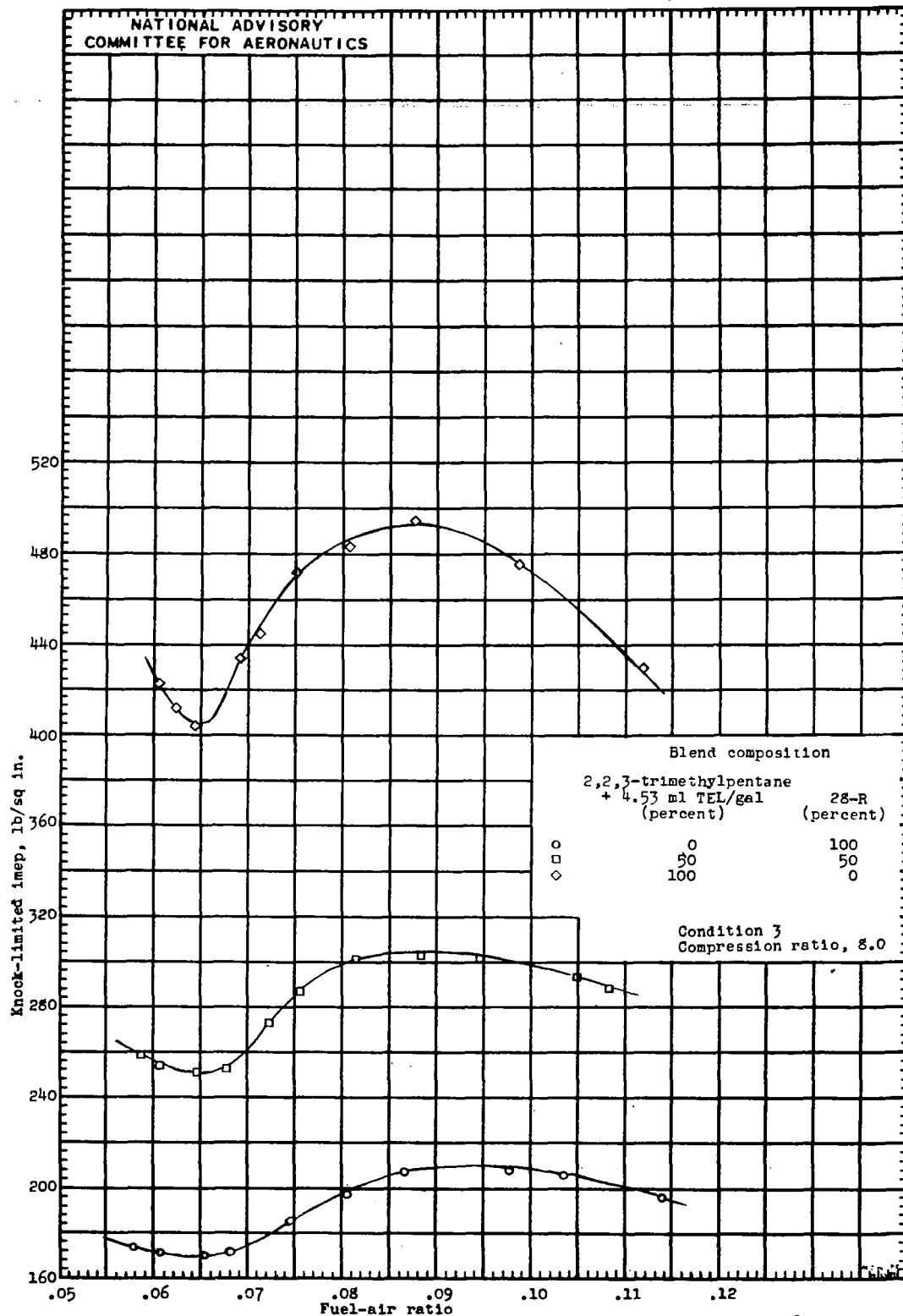
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Figure 2. - Continued.



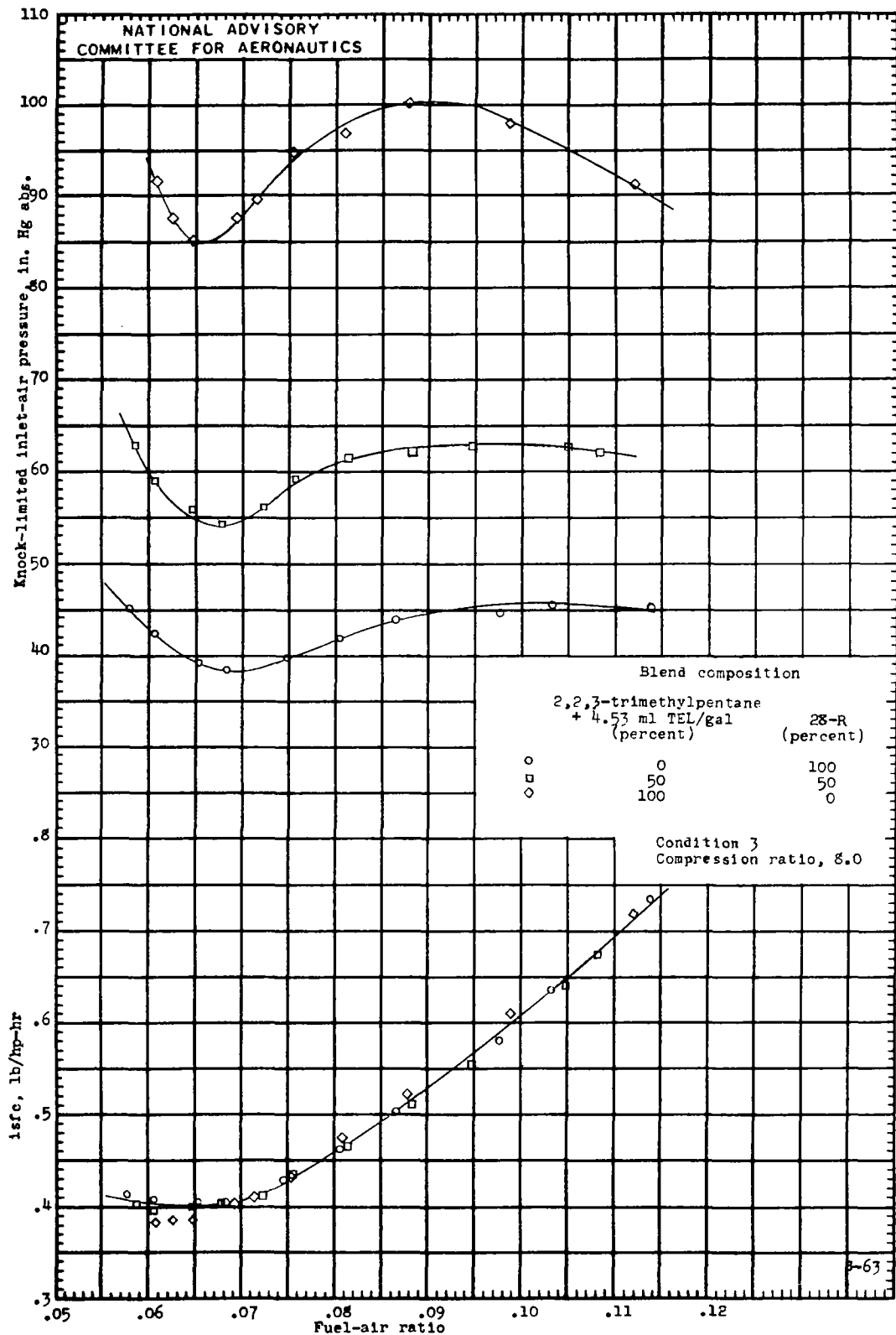
(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 2. - Continued.



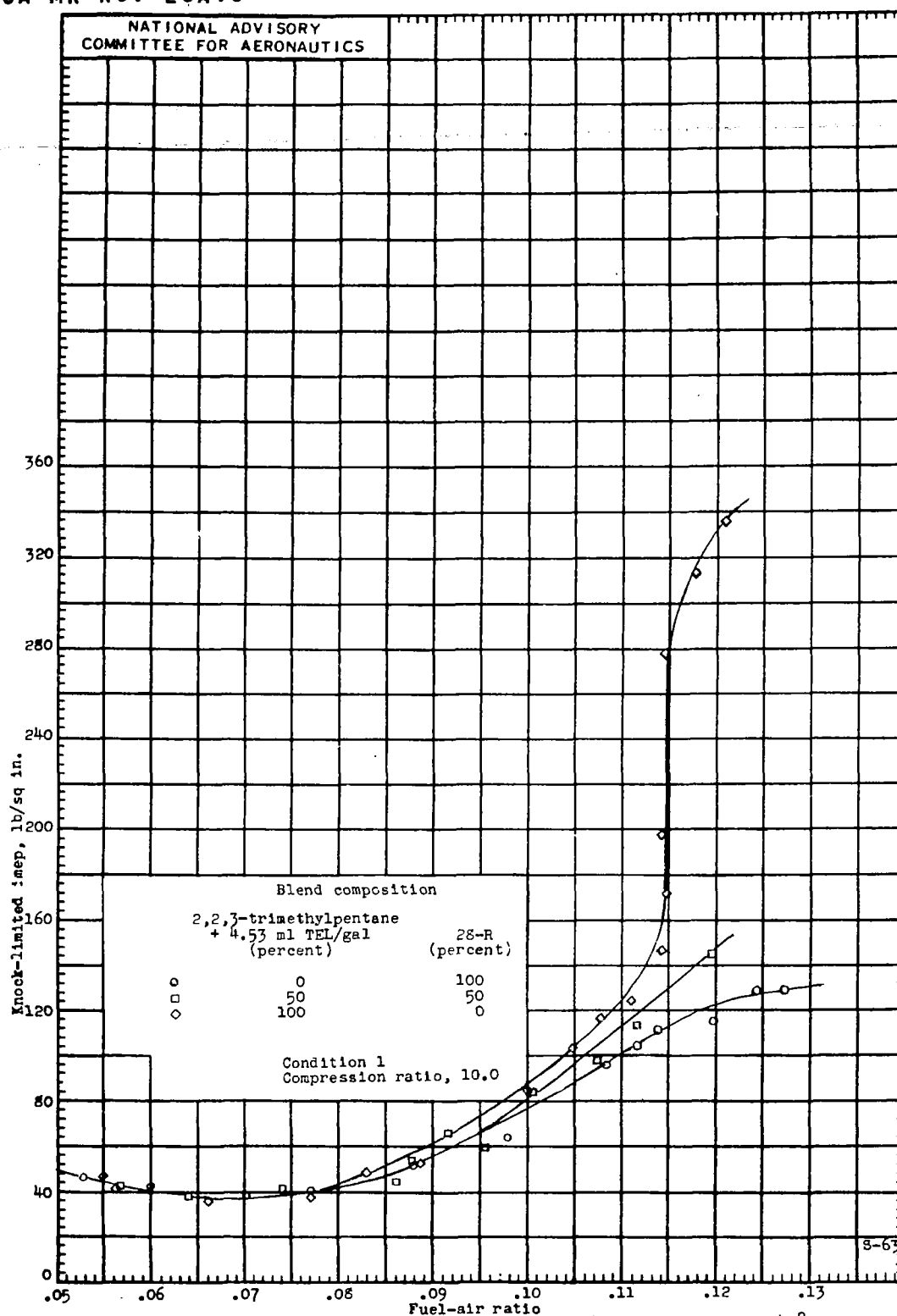
(b) Concluded.  
Figure 2. - Continued.



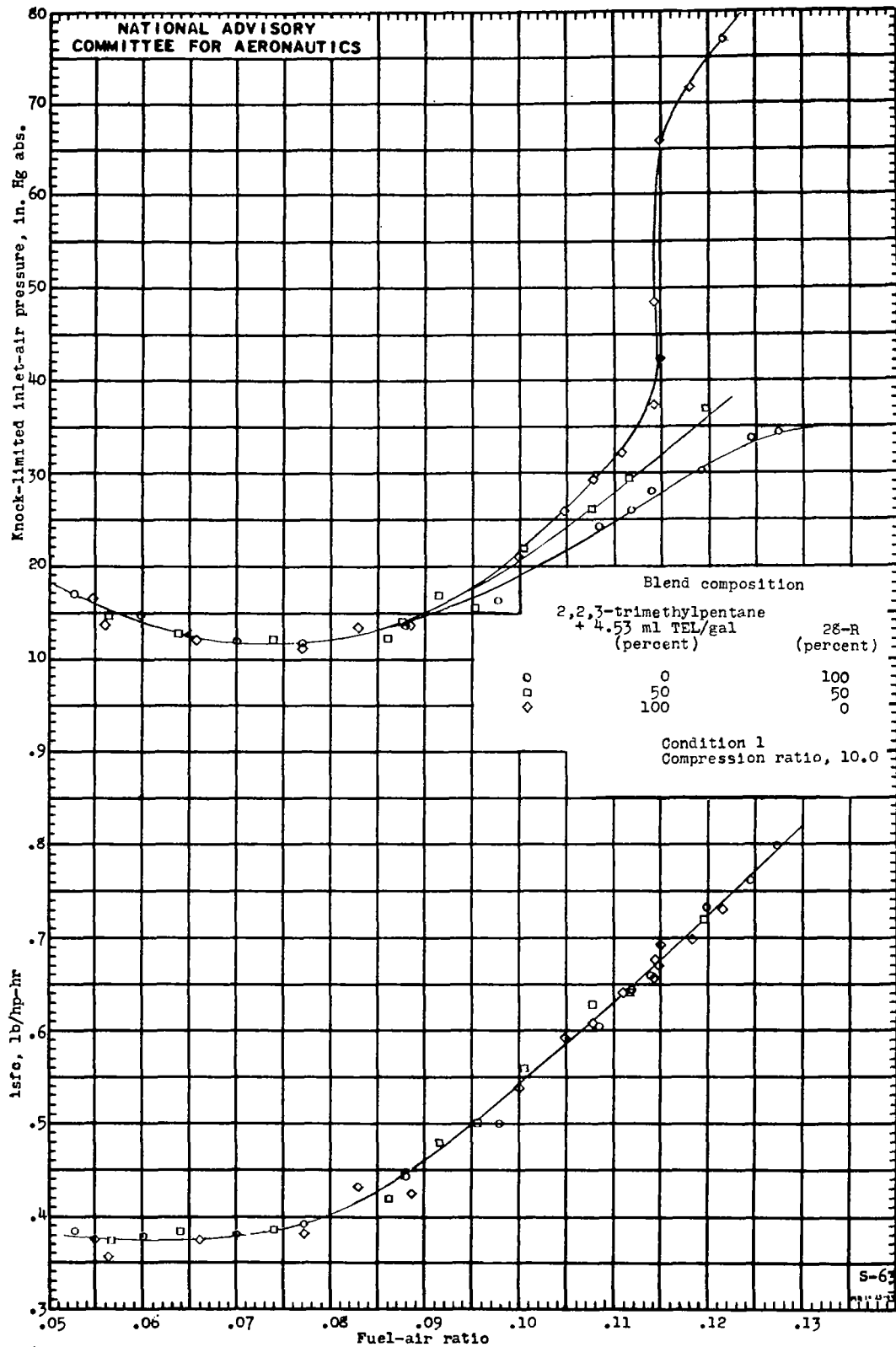
(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 2. - Continued.



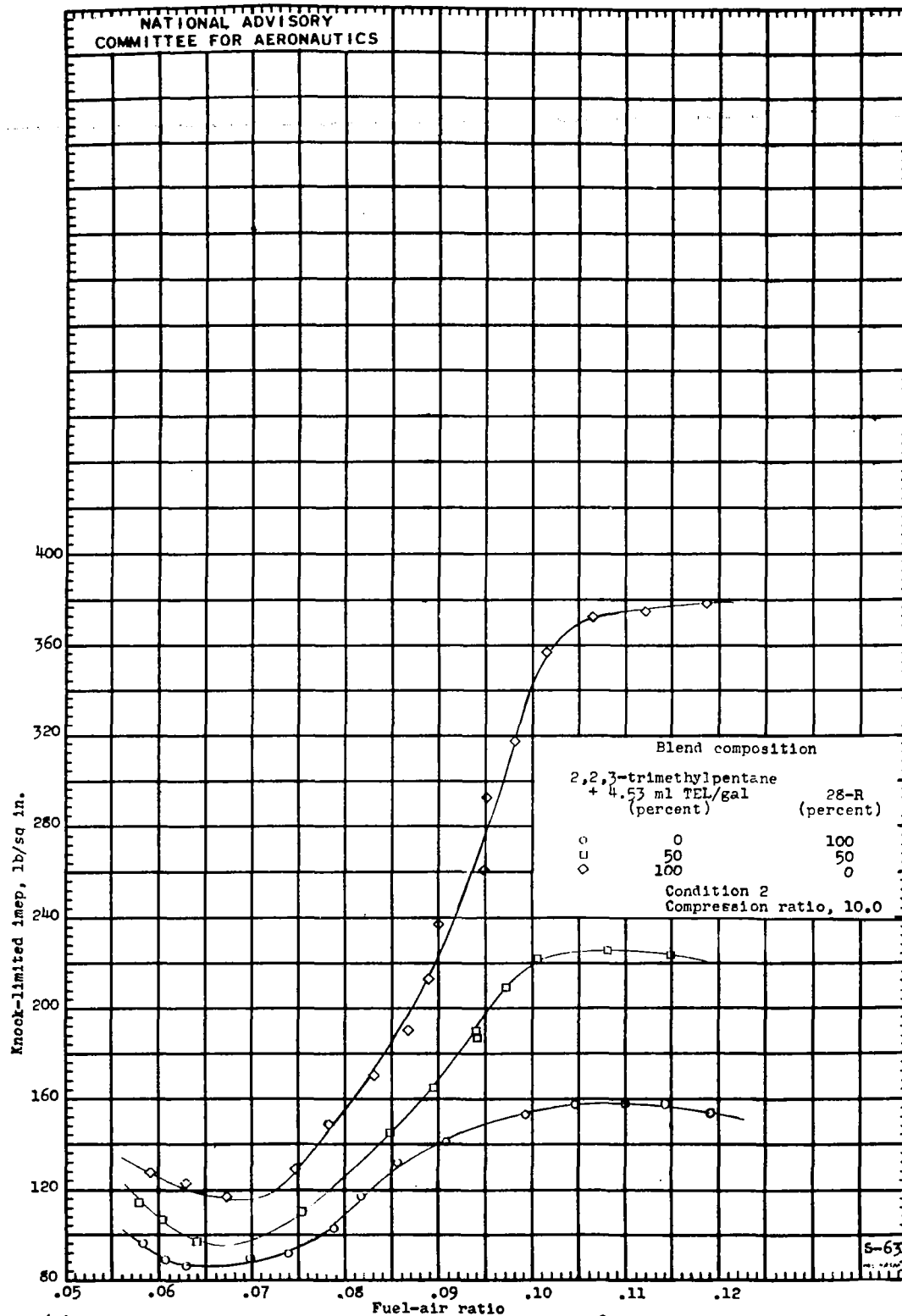
(c) Concluded.  
Figure 2. - Concluded.



(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.  
Figure 3.-- Knock-limited performance of blends of 2,2,3-trimethylpentane and 28-R fuel  
in CFR engine at compression ratio of 10.0. Engine speed, 1800 rpm; oil temperature,  
165° F.

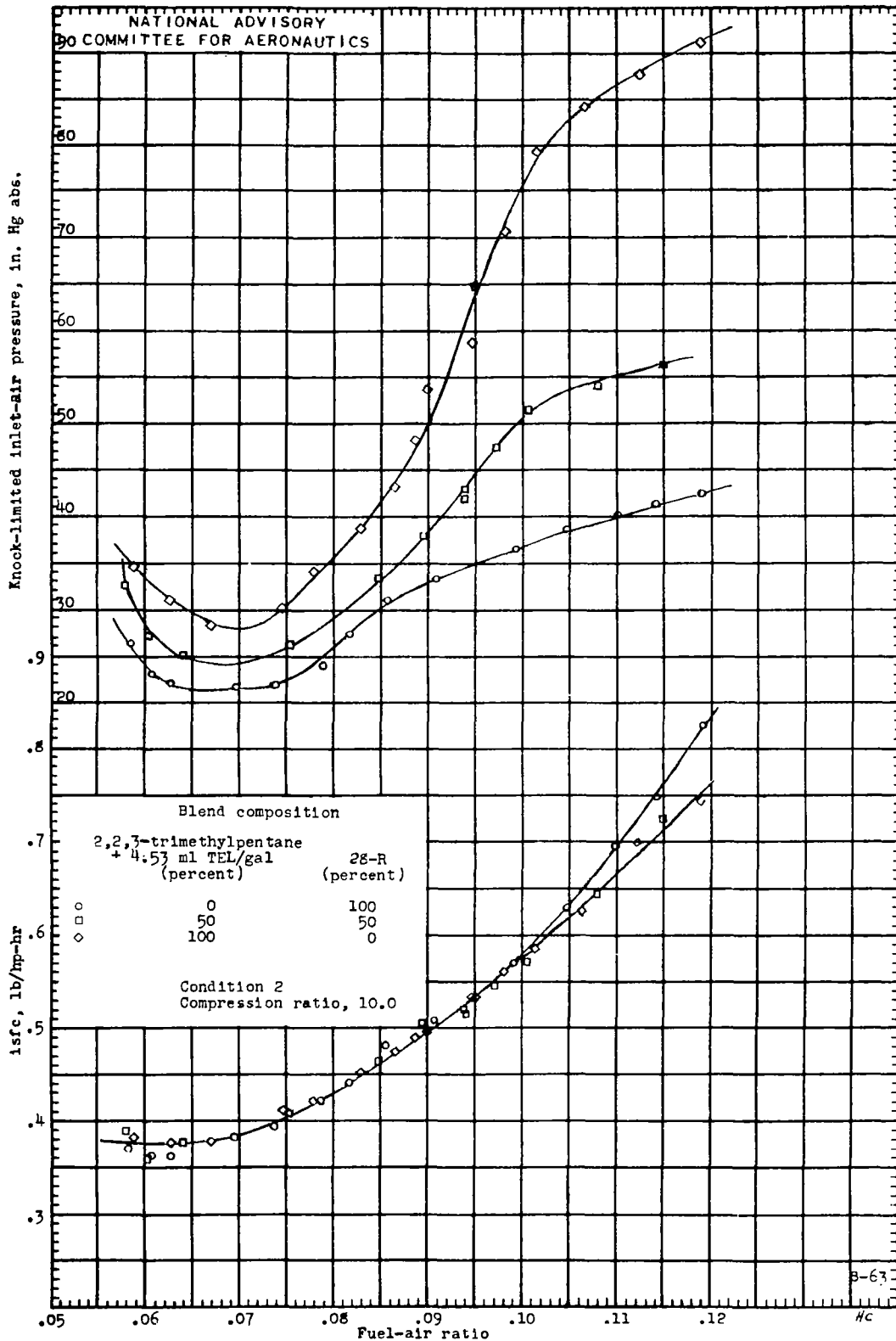


(a) Concluded.  
Figure 3. - Continued.

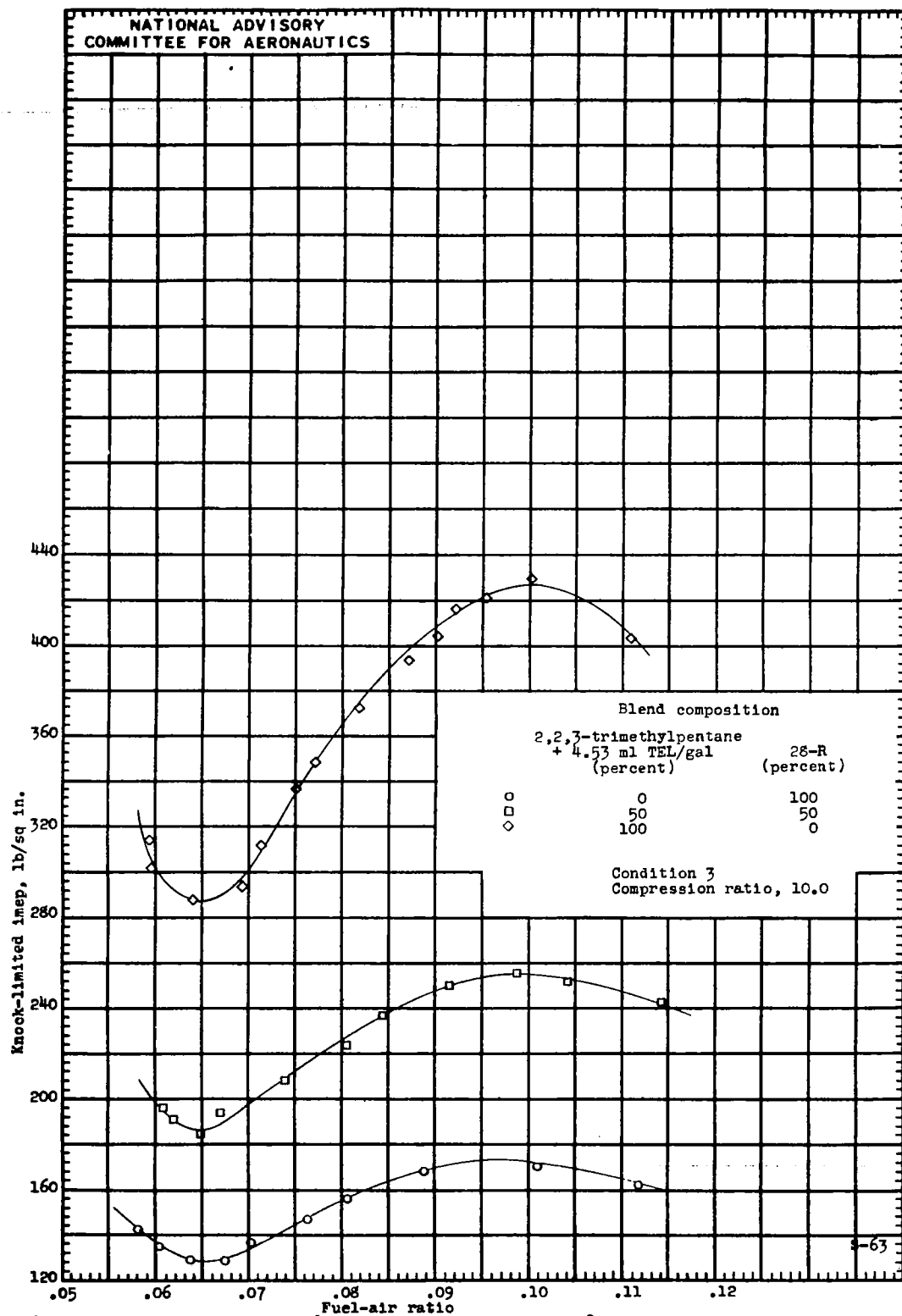


(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 3. - Continued.

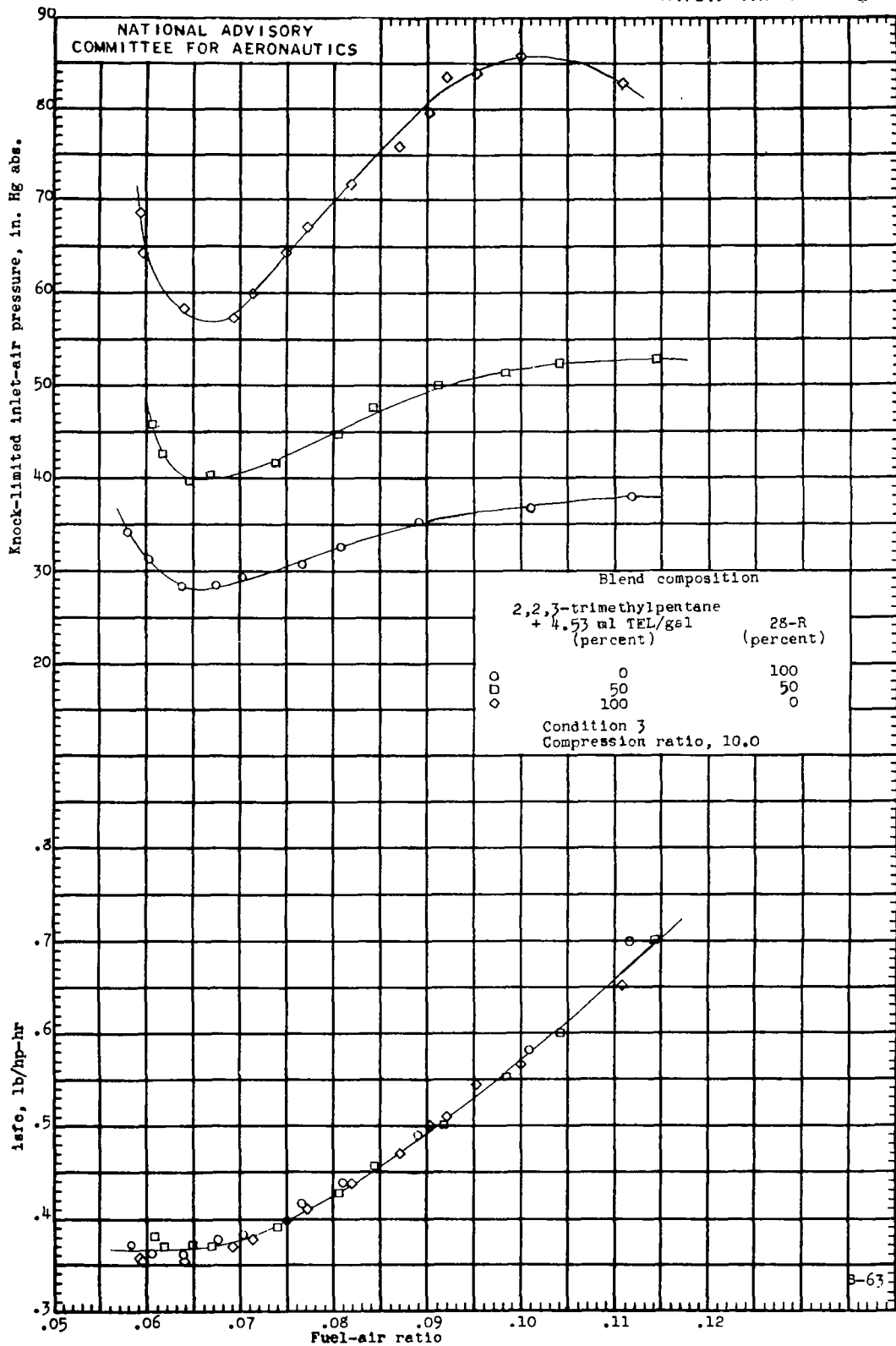




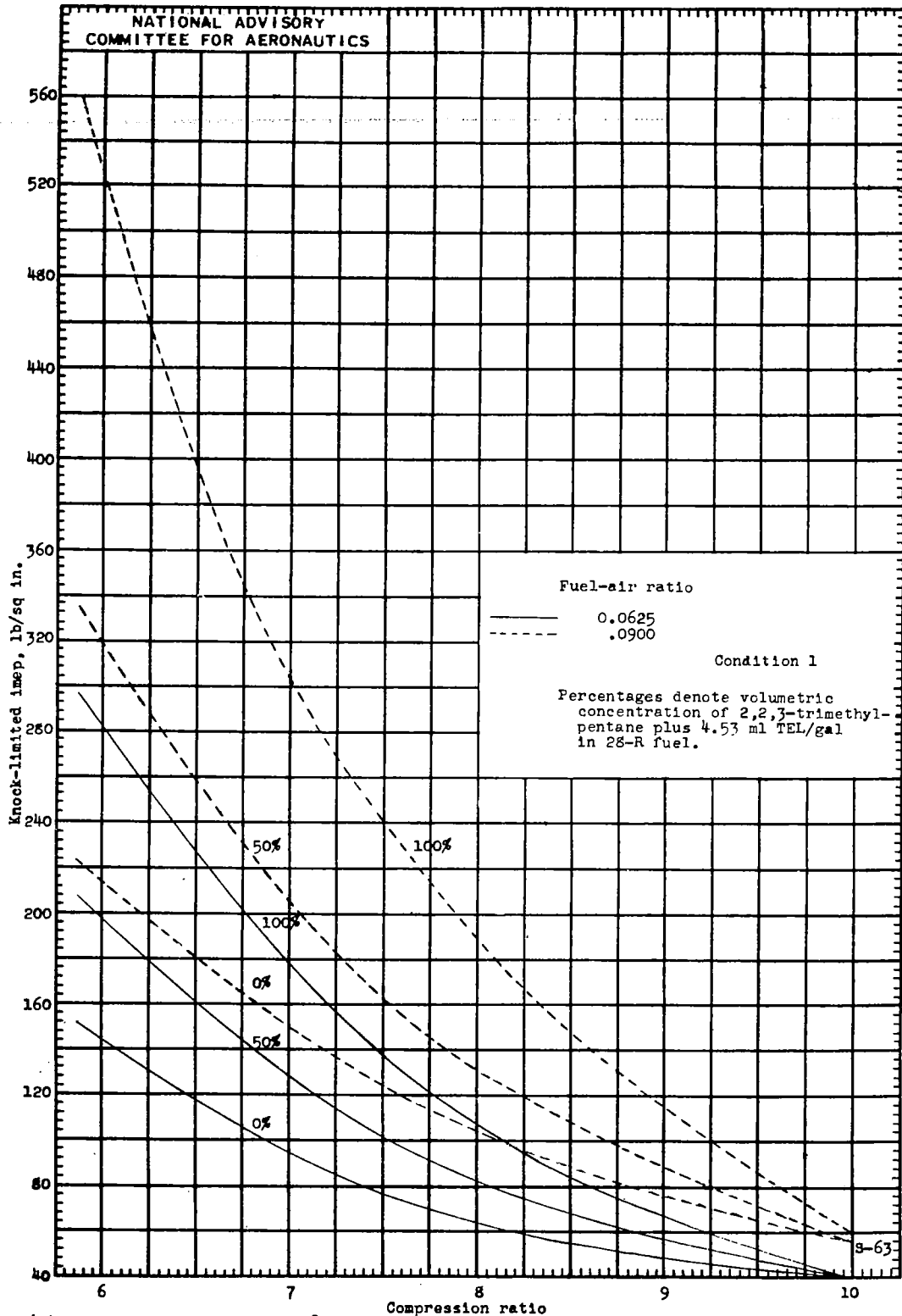
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Figure 3.- Continued.



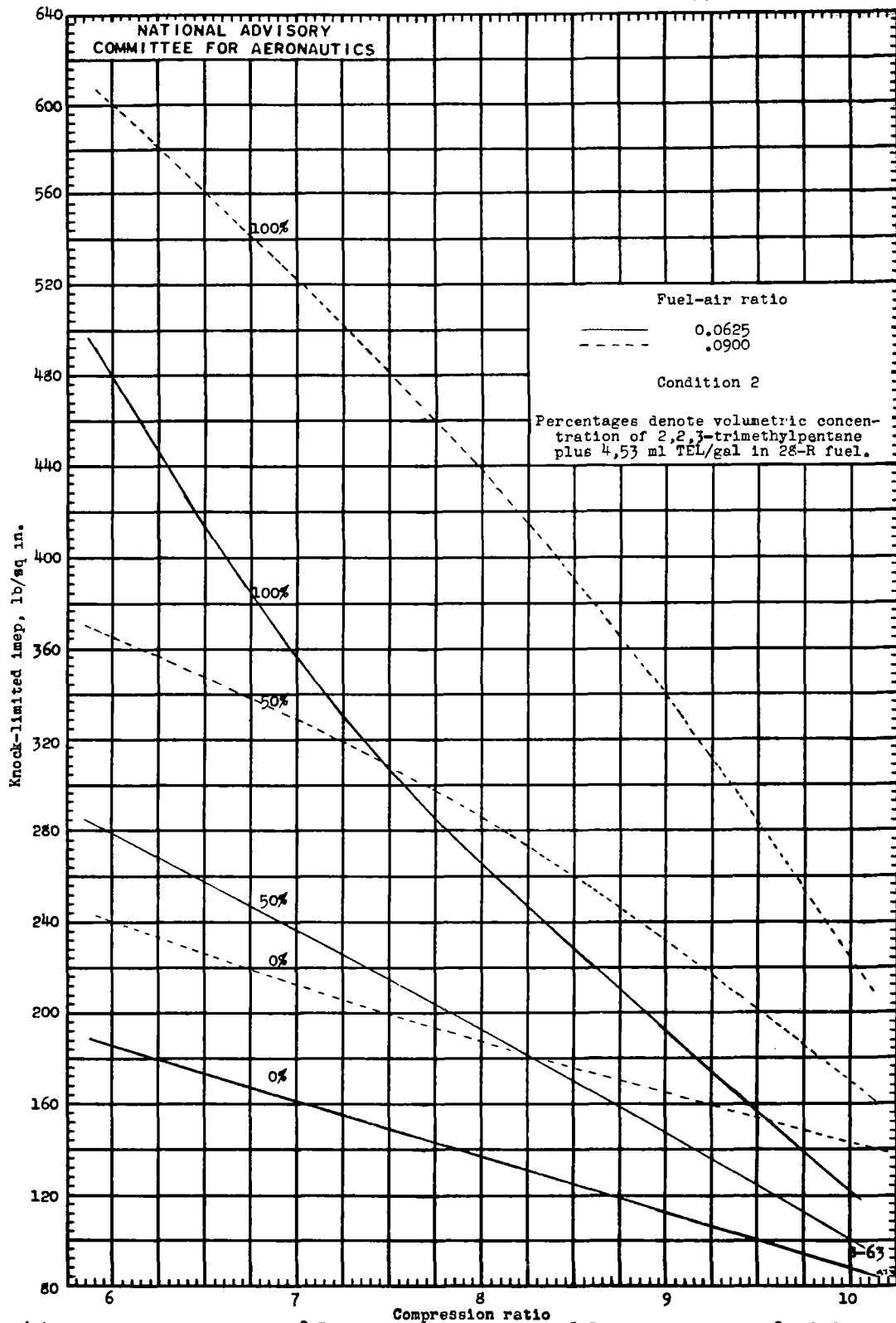
(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 3. - Continued.



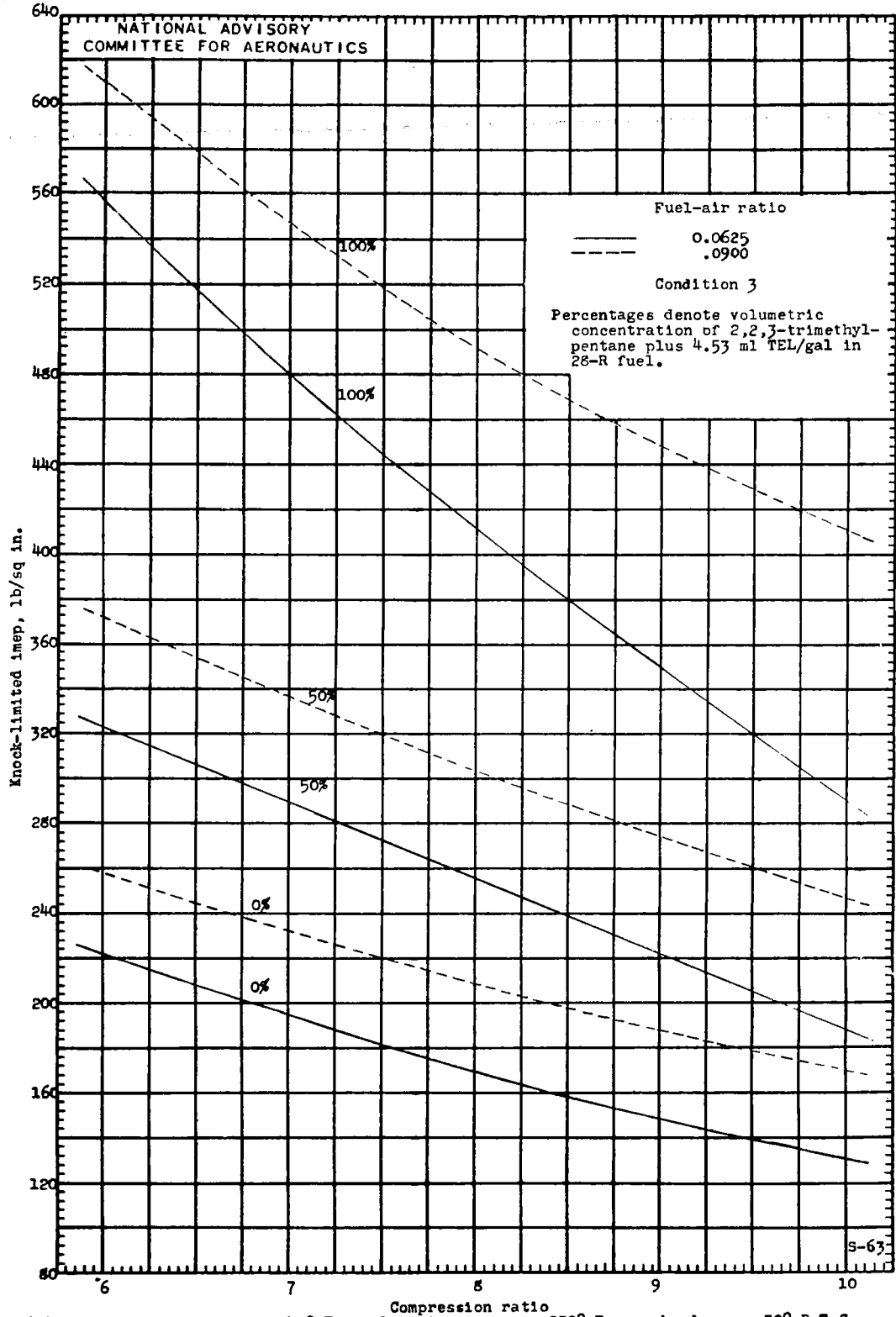
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Figure 3. - Concluded.



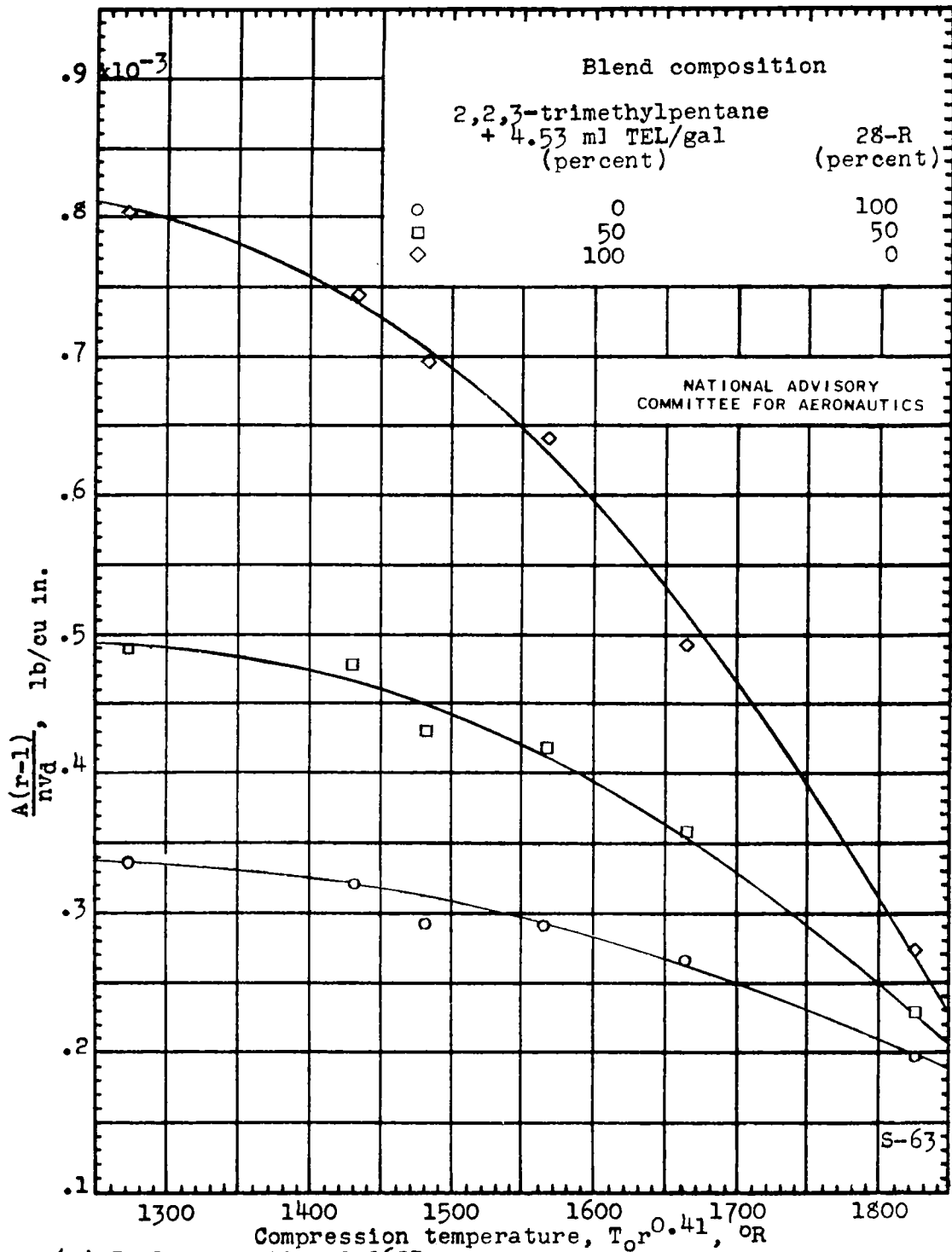
(a) Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.  
 Figure 4. - Effect of compression ratio on knock-limited performance of 0, 50, and 100 percent 2,2,3-trimethylpentane in 28-R fuel at fuel-air ratios of 0.0625 and 0.0900.



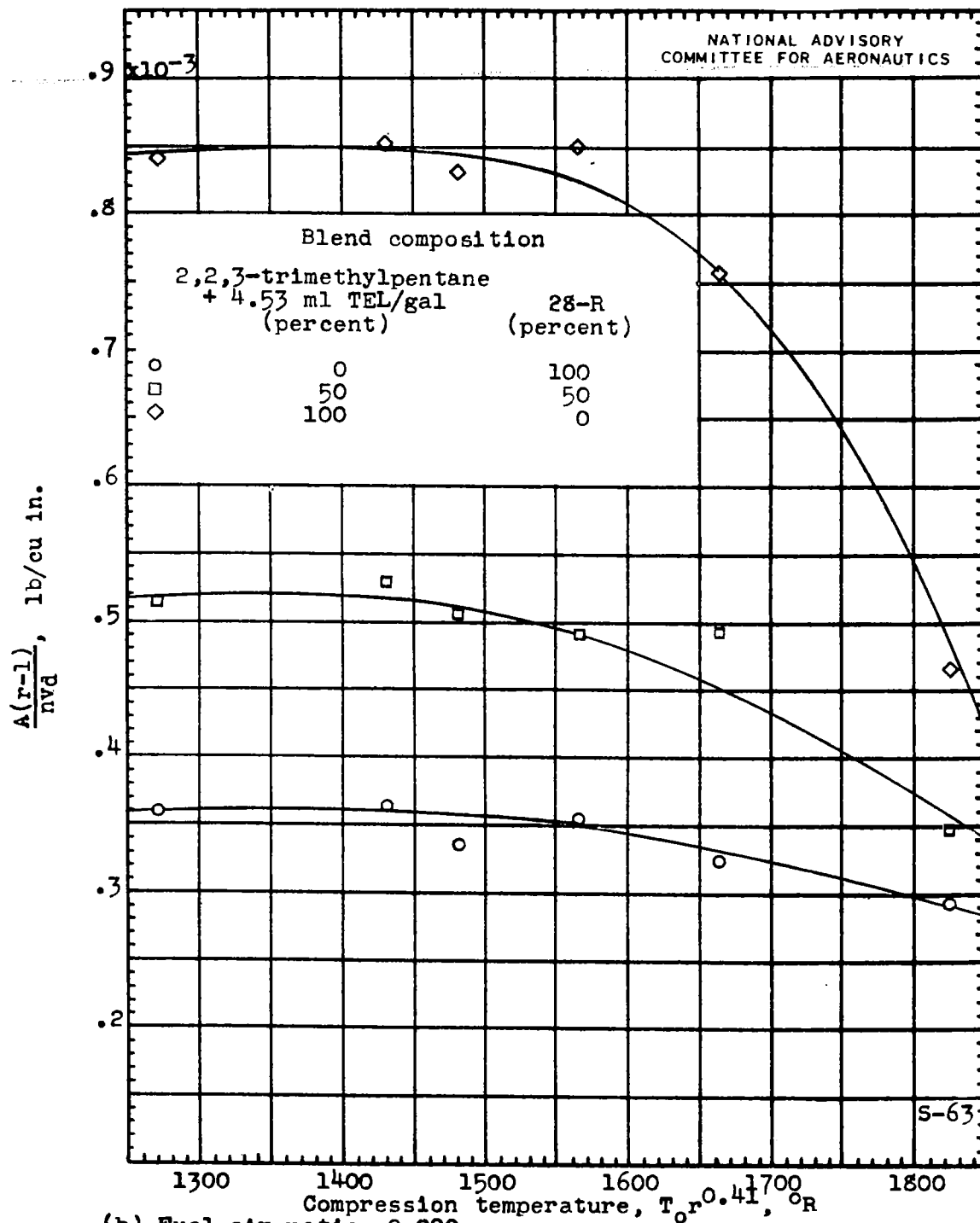
(b) Inlet-air temperature, 250° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
 Figure 4. - Continued.



(c) Inlet-air temperature, 150° F; coolant temperature, 250° F; spark advance, 30° B.T.C.  
Figure 4. - Concluded.

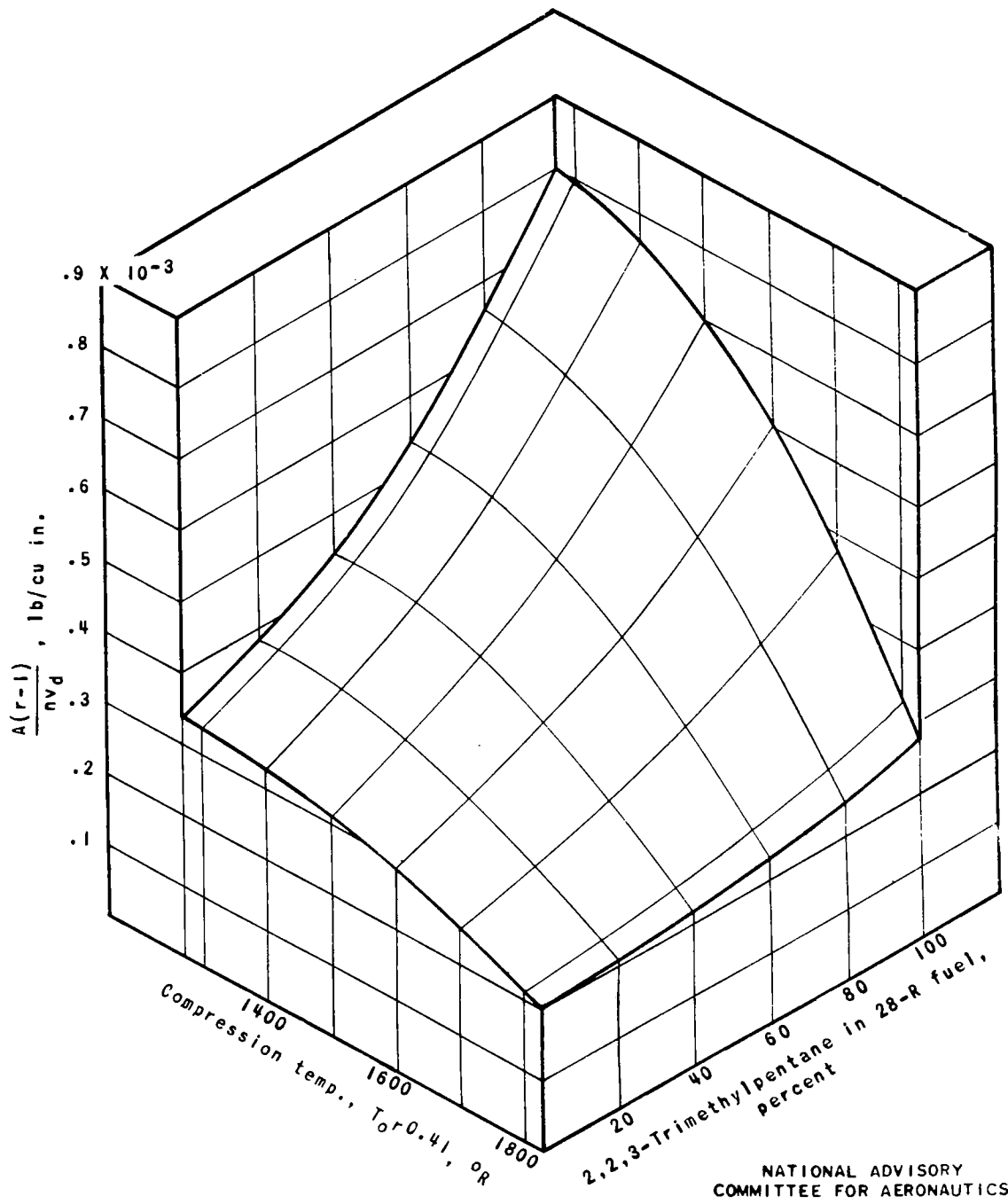


(a) Fuel-air ratio, 0.0625.  
 Figure 5. - Effect of compression temperature on knock-limited compression-air density  $\frac{A(r-1)}{nv_d}$  for blends of 2,2,3-trimethylpentane and 28-R fuel. Data calculated from figures 1, 2, and 3.



(b) Fuel-air ratio, 0.090.  
Figure 5. - Concluded.

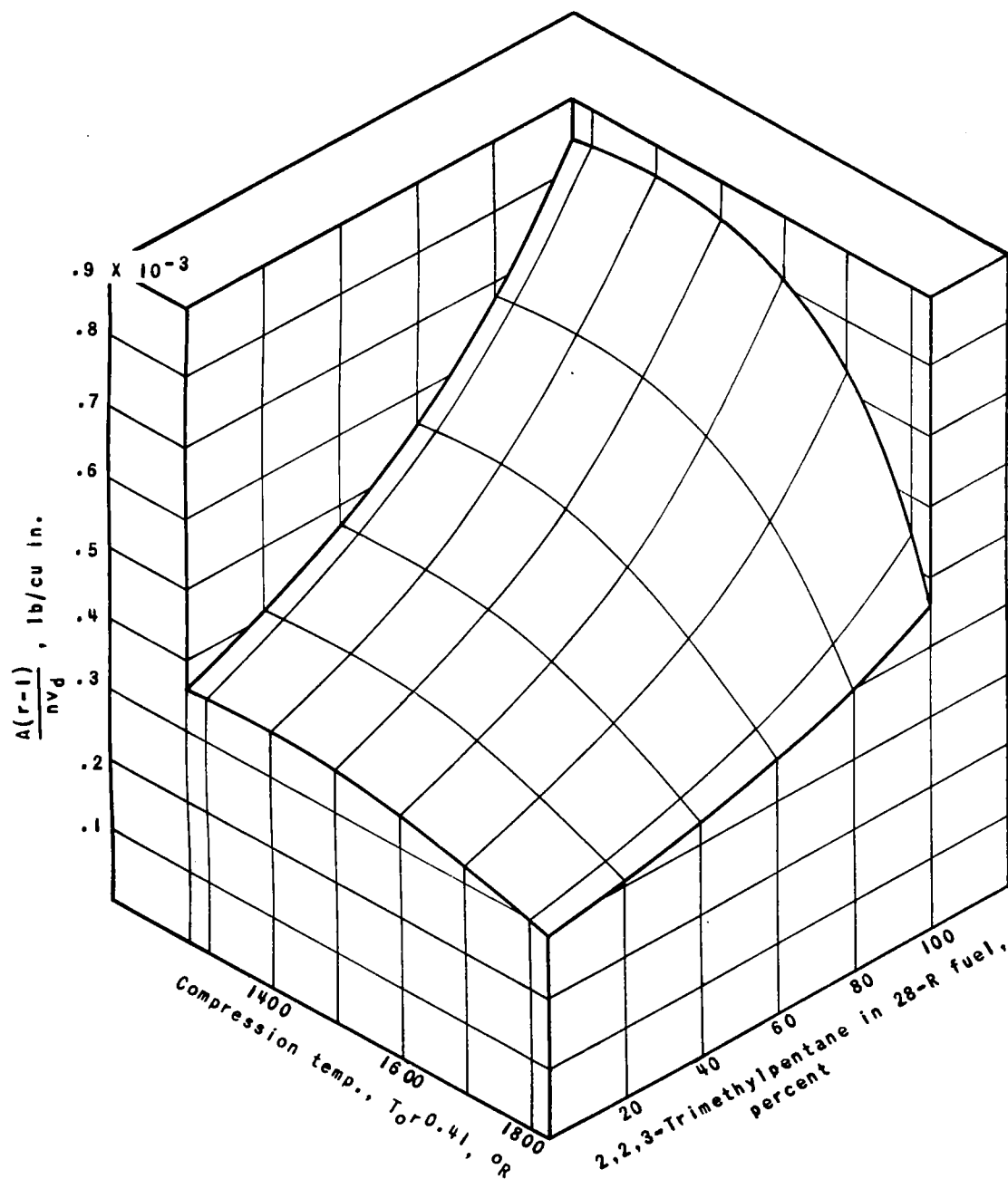




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(a) Fuel-air ratio, 0.0625.

Figure 6. - A correlation of blend concentration, compression temperature, and knock-limited compression-air density  $A(r-1)/nv_d$  for blends of 2,2,3-trimethylpentane and 28-R fuel. Data calculated from figures 1, 2, and 3.



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(b) Fuel-air ratio, 0.090.

Figure 6. - Concluded.

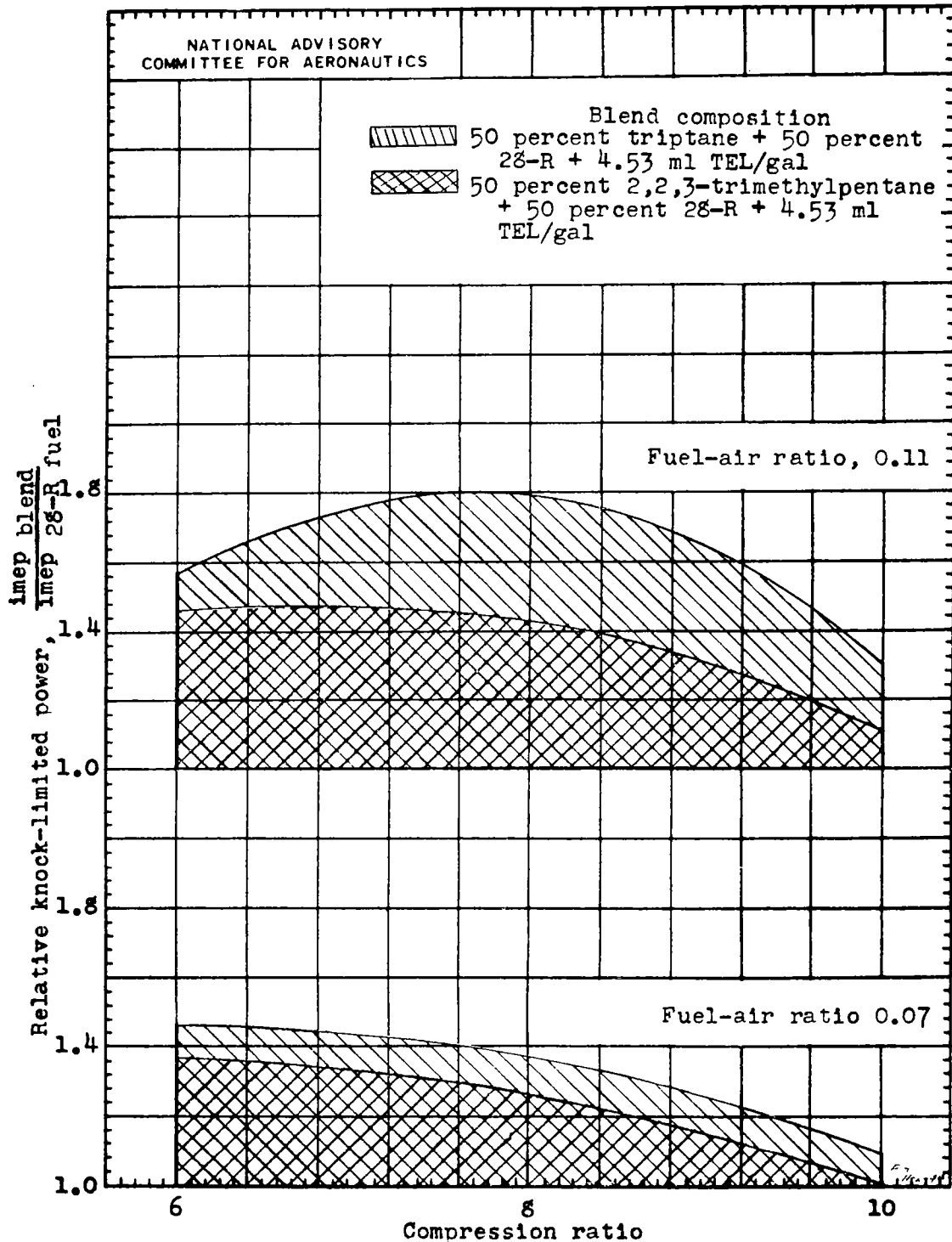


Figure 7. - A comparison of the relative effectiveness of triptane and 2,2,3-trimethylpentane when blended with 28-R fuel. Inlet-air temperature, 225° F; coolant temperature, 375° F; spark advance, 45° B.T.C.; engine speed, 1800 rpm; oil temperature, 165° F.

